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THE OIL SHALES OF THE SCOTTISH CARBONIFEROUS SYSTEM.

THE Lower Carboniferous Rocks of the east of Scotland have within the last quarter of a century attained great economic and geological interest from the oil-bearing shales they have been found to contain. The district around Edinburgh is one of great complication, and until the operations of the shale mines began large parts of the ground which is usually deeply covered with glacial drift were geologically but imperfectly explored. It is only recently that the chief oil shale districts have been mapped correctly, and the new edition of the geological map of the Edinburgh district, on which I have been engaged for several years tracing out the oil shale outcrops, etc., has only been published within the last six months. A detailed account of the structure of this area has not yet been published, and beyond a few short papers by myself and others in various scientific journals, nothing of importance has been written on this interesting subject.

The Carboniferous system of Scotland is broadly divisible into the following groups:

4. *Coal Measures, with the most important coals.*
3. *Millstone grit, chiefly barren sandstones.*
2. *Carboniferous Limestone Series, with beds of limestone above and below, and shales, sandstones, etc., interbedded with seams of excellent coal in the center.*
1. *Calciferous Sandstone Series, with sandstones, estuarine limestones, marls, seams of oil shale and occasional impure coal, the*

base of the series consisting of coarse red sandstones, shales and marls resting on the Old Red Sandstone.

The oil shales of Scotland are confined almost exclusively to the "Calciferous sandstone" strata in the Edinburgh district, and the principal seams occur in West Lothian, where the most important oil works are situated, about twelve miles west of the Scottish metropolis.

Broadly speaking, Edinburgh is situated on a great anticline, in the center of which there rises a ridge of Silurian and Old Red Sandstone rocks, partly igneous and partly sedimentary, whose general strike is northeast and southwest. The hard volcanic strata and igneous intrusions in these older rocks have produced most of the pictureque ranges of hills in the vicinity of Edinburgh, and the softer beds in the higher parts of the series dip away, with many complications, from either side of the central axis. To the east of the Pentland ridge the inclination of the beds is very high, and comparatively regular, and consequently the whole thickness of the calciferous sandstone series can be traversed in a short time. There is also here a large fault running along the base of the hills which conceals the lowest of the calciferous series of rocks and brings up the old volcanic beds against the upper parts of the oil-bearing strata, and indeed at one place the dislocation has been so great that the calciferous rocks with their oil shales are almost entirely hidden, and the upper beds of the Old Red Sandstone abut almost directly on the base of the marine limestone series.

The Carboniferous limestones along this line, with their interbedded coal seams, are inclined for long distances at the same high angle and plunge at places almost vertically downwards beneath the long and regular trough of Dalkeith Coal Measures, from which they emerge five or six miles farther east at a much lower inclination.

To the west of the Edinburgh anticlinal the structure of the district is much more complicated. The Calciferous rocks spread out for fifteen or sixteen miles in a tumultuous sea of undulations, basins and folds cut up by multitudes of faults, and

traversed by numerous necks, sheets and dykes of intrusive igneous rock, to map which, even with the aid of copious mining information, is often a task of the greatest difficulty. The rapid thinning and thickening of some of the members of the series also adds an element of difficulty to the elucidation of the structure of the district, and although many hundreds and even thousands of borings have been made in search of oil shale and other rocks, there are places where, in the absence of surface exposures, the structure of the area has still to be ascertained.

The total thickness of the Carboniferous Limestone series of Mid and West Lothian is about 2,000 feet, and that of the upper or oil shale division of the underlying calciferous series is a little over 3,000 feet. Beneath the oil shale series there is a group of shales, fire clays and gray sandstones, one of which, formerly quarried very extensively at Craigleith, supplied nearly all the celebrated freestone from which a large part of the New Town of Edinburgh was built. Owing to its great hardness and cost of working the Craigleith stone has now been nearly given up and is only used where great strength is wanted in house architecture, or for export to America, where it appears to be used occasionally for special work. This middle division of the Calciferous Sandstone series appears to be about 3,000 feet thick, and the red beds which lie below cannot be much thinner, so that 9,000 feet may be taken as the approximate distance from the top of the Old Red Sandstone to the highest part of the Oil shale series in this locality.

Dealing now in greater detail with the Oil shale group of rocks, it may be noted, first, that the whole series has a fresh water or estuarine character, and contains few or no strata of a marine type. There are numerous thin bands of concretionary unfossiliferous limestone, and one well-marked bed of richly fossiliferous estuarine limestone of workable thickness. This rock—the Burdiehouse Limestone—in addition to fresh water shells, contains fish plates, teeth, etc., and many plant remains such as *lepidodendron* and *sphenopteris*, and is at places directly

covered by a bed of black bituminous shale of inferior oil-producing quality. The series is also characterized by numerous well-marked beds of unfossilferous red, green and gray marl, the origin of which is not very clear, but as the marl is seen at places to contain pieces of felspathic volcanic ash, it seems reasonable to suppose that it may be made up in part at least of impalpable mud derived either from volcanic dust or from the disintegration of some old volcanic area which has now disappeared from view, but which formed part of the ancient mainland from which the other sediments were derived. There is no distinct evidence of volcanic action during the greater part of the Oil shale period in the Lothians, and the numerous ash necks which pierce the strata were probably connected with the extensive outbursts which took place during the subsequent Carboniferous Limestone period. Many beds of gray and yellow sandstone are found interbedded with the oil shales as well as impure coals, fire clays, and non-bituminous carbonaceous shales —the "blaes" of the Scottish mines, in which plant remains, and fresh-water molluscan forms are at places found in abundance.

The Scottish Oil shales are simply beds of very fine impalpable clay shale highly impregnated with hydrocarbon, easily distinguished in the field by their resistance to the disintegrating action of the weather, thin brown streak, and the facility with which they can be cut and curled up with a sharp knife. The texture is at times tough, almost leathery, and thin pieces are slightly flexible and easily distinguishable from ordinary black carbonaceous "blaes" with which they are often closely associated. When lit with a match oil shale burns, as a rule, brightly, leaving a finely laminated skeleton of ash after all the hydrocarbon has been exhausted. On distillation the yield of oil varies. Good shales should give, per ton, at least thirty gallons of crude petroleum, as well as enough ammonia to produce, when neutralized with sulphuric acid, from ten to fifty pounds of sulphate of ammonia. This product is often as valuable as the oil, and much skill has been employed in the construction of retorts to extract it completely. The crude oil when refined gives various

products, such as tar, naphtha, paraffin, light illuminating and heavy lubricating oils, and the oil industry of the Lothians was for more than a quarter of a century a source of great profit and employment to the capitalists and operatives of the district, but of late years the severe competition with foreign producers has made most of the works quite unremunerative. The thickness of the oil shale beds varies considerably from place to place, and it is quite common to find a good seam thinning out in one district and passing into ordinary carbonaceous shale, or disappearing altogether, while another seam above or below it may improve in quality in proportion as the first deteriorates. The Broxburn shale—the richest seam in the Broxburn district—varies in thickness from about two and a half to eight feet, and the Dunnet shale reaches at places a workable thickness of thirteen feet.

An interesting phenomenon is observable at some places where the strata have been heated by igneous intrusions. In these cases if an oil shale bed has been affected by the heat, partial distillation has followed, and the surrounding rocks, including the eruptive sheet itself, have become impregnated with the hydrocarbonaceous ingredients expelled from the shales. In a recent diamond boring a core of the eruptive dolerite was brought up from a depth of over 600 feet, traversed by veins of solid paraffin, which melted when the rock was laid in the sun, and at the outcrop of this intrusive sheet it is found to contain cavities filled with tarry matter and to give off a strong bituminous odor when freshly broken with the hammer. This eruptive sheet has forced its way for miles through strata adjoining the Broxburn shale, and whenever it has touched or even approached the shale the seam has of course become quite worthless economically. The well-known sandstone of Binney, which is located some fathoms below the Broxburn shale, has long been known to contain veins of ozocerite or an allied hydrocarbon, and the quarrymen used formerly, when the rock was extensively worked for building and monumental purposes, to make black candles of the substance, some

of which are still preserved in the Science and Art Museum in Edinburgh. There can be little doubt that this "mineral" owes its origin to the distillation of the bituminous matters by the igneous intrusions in the vicinity of the overlying oil shale.

The oil shales occur within an area roughly twenty miles in diameter. On the north shore of the Firth of Forth only one seam of workable quality is known, and all the others have apparently disappeared and become replaced by more arenaceous rocks, while in the Lower Carboniferous deposits in other parts of Scotland no oil shales of any value have been yet discovered. These valuable deposits appear to have been found in broad lagoons into which vegetable matter was brought in a very fine state of division, and laid down along with a small quantity of inorganic silt under conditions of great tranquillity. That the hydrocarbon is however sometimes of animal origin is clear from the quantity of cyprids that make up some of the shales. Large plant remains are rare, but beautifully preserved fronds of *sphenopteris affinis*, and other ferns are abundant in some of the beds of oil shale. There cannot have been currents of any strength sweeping through the lakes of the Scottish oil-shale period, otherwise the light organic particles would have been at once swept away, and this order of things must, with periodical interruptions, have obtained within the shale region for a long succession of ages, during which deposits accumulated to a depth of over 3,000 feet.

Liquid petroleum has been occasionally found exuding in small quantities from the joints of these sedimentary rocks, and there is at St. Catherines, about three miles south of Edinburgh, a spring situated on the line of the great fault east of the Pentland axis already referred to, known for many centuries as the Balm Well, whose surface is covered by a film of mineral oil derived no doubt from the slow distillation of the oil shales on the downthrow side of the dislocation. We cannot, however, boast of anything like the famous oil wells of Pennsylvania, which I had the pleasure of visiting in 1891, and even were there rich oil sands among the Califerious sandstones of the

Scottish Lothians, the exceeding faulted and disturbed nature of the Carboniferous system in this locality would effectually prevent the circulation underground of any quantity of fluid hydrocarbons except within extremely limited areas.

The following is a general section of the oil shale series west of Edinburgh:

	FEET.
Strata below base of Carboniferous Limestone series about	400
Raeburns Shale, 3 to 4 feet strata, - - - - -	190
Mungals Shale, about 1 ft. 9 ins. strata, - - - -	170
Coal and Gray cypride Shale 2 ft. "Houston Marl" group	200
Strata laminated sandstones, - - - - - -	240
Fells Shale, 3 to 5 feet, "Broxburn Marl" group, 80 to	270
Broxburn Shale 2½ to 8 feet, "Binney Sandstones" and strata, - - - - - - - - - -	450
Dunnet Shale, 6 to 13feet, strata chiefly shales, fire clays, etc.	400
Barracks Shale, resting on the estuarine Burdiehouse Limestone, 10 to 50 feet thick at places, strata about -	780
Pumpherston Shales, about 6 feet worked.	
Apparent thickness of Oil shale series, - - -	3,100

HENRY M. CADELL.

THE CRETACEOUS RIM OF THE BLACK HILLS.[1]

As is well known, the Black Hills District was surveyed by the party in charge of Professor W. P. Jenney in 1875, the geological report being written by Professor Henry Newton, whose death occurred two years later. The report, edited by Mr. G. K. Gilbert, was published in 1880 by the U. S. Geographical and Geological Survey of the Rocky Mountain Region in charge of Major J. W. Powell. The peculiar and interesting geological features of this remarkable outlier of the Rocky Mountain range need not be set forth here further than to say, that on all sides after leaving the central nucleus of eruptive rocks sedimentary deposits occur with diminishing dip in an ascending geological order. First, there is a narrow ring of Potsdam sandstone; then a wide belt of Carboniferous limestone; next an encircling trough, aptly compared by Professor Newton to a moat, of red sandy gypsiferous clays, in which is included a purple limestone terrace, all of which is supposed to be Triassic and to be the equivalent of the "Red Beds" of more southern regions; skirting this is a very narrow border of highly fossiliferous light colored Jurassic clays or marls; then come the foot-hills, which consist of Cretaceous sandstones and shales referred by Professor Newton to the Dakota, No. 1, of Meek and Hayden's section; these slope back to the dark shales of the Fort Benton group, which are succeeded by higher Cretaceous beds that extend to the plains and pass under the Bad Lands of the White River formation.

The belt of Cretaceous, which lies outside the Red Beds and Jurassic and forms the foot-hills, constitutes an elevated rim with an escarpment at its inner margin rising abruptly above the Triassic trough, the Jurassic exposures being often confined to the lower part of the escarpment. This cannot be better rep-

[1] Published with the permission of the Director of the U. S. Geological Survey.

resented than in the following figure copied from Professor Newton's report:[1]

At that date the opinion widely prevailed that there was no Lower Cretaceous in North America. The Shasta, Kootanie, and Comanche groups were unknown, the Potomac of Virginia was supposed to be "Upper Oolite," and the Iron Ore Clays of Maryland and Plastic Clays of New Jersey were classed as Wealden and referred to the Jurassic. Meek and Hayden had been unable to find any Cretaceous deposits lower than No. 1 of

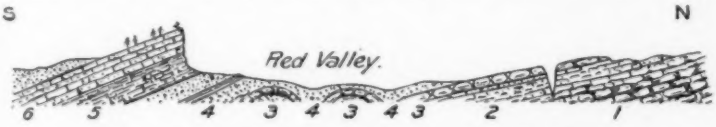


FIG. 1.—Ideal section across Red Valley on Amphibious Creek.

1. Carboniferous.
2. Red sandstones and clay (Red Beds).
3. Purple limestone (Red Beds).
4. Red clay with gypsum (Red Beds).
5. Jura.
6. Cretaceous sandstone capping the foot-hills.

their famous section, and this was believed to be the oldest Cretaceous deposited on this continent, which was supposed in some way to have been out of water during the entire period that separated this from the Jurassic.

My attention was first attracted to the Black Hills by a letter received at the Smithsonian Institution in February, 1893, from a resident of Hot Springs, South Dakota, inclosing photographs of certain petrifactions found in that vicinity which he said had been called "Cycads." The letter and photographs were referred to me on the presumption that these objects were of vegetable origin. I at once perceived that they were fossil cycadean trunks closely resembling those collected by Tyson in 1860 in the Iron Ore Clays of Maryland and named by Professor Fontaine *Tysonia Marylandica*, and, therefore, also similar to the forms found by Mantell and others in the early part of the cen-

[1] Geol. Black Hills of Dakota, p. 141, fig. 20.

tury in the Purbeck beds on the Isle of Portland and at other points in the South of England. Being greatly interested in the discovery, I recommended that the proprietor be requested to send on a specimen for examination. The request was complied with, and the specimen proved to be all that I had expected. I therefore made the further recommendation that negotiations be entered into with a view to the purchase of the collection of six specimens which were offered for sale. This was also successful and the collection arrived in May.[1] One of the chief features of these specimens is the great size of some of them, the largest measuring 30 inches in height, 2 feet in its longest diameter, and weighing 900 pounds, thus far exceeding anything of the kind hitherto known from any other part of the world.

Fossil remains of cycadean trunks range from the Upper Trias to the Lower Cretaceous. A number have been found in the clay shales of Italy which have been referred to the Cenomanian, but will probably be found to be lower. Hot Springs is located on the Red Beds in the valley of the Minnekahta creek, or Fall River, and it would have been natural to suppose that the cycad trunks had come either from these or from the Jurassic which borders it, had it not been stated that they were found "on a high hill." My interest was of course strongly aroused to know the stratigraphical position of the beds in which they occurred, and therefore early in September I made an expedition to the region for the purpose of determining it if possible. I had previously corresponded with Mr. F. H. Cole, of Hot Springs, from whom the specimens had been purchased. I had also written to Professor Jenney, who was then at Deadwood, and who kindly consented to join me on my arrival and aid me in the investigation. After considerable search and some difficulty the locality was at length found. It is some four miles southwest of Minnekahta Station, about two miles west of Minnekahta Creek, which here has a northward course, on foothills one and a half miles east of the divide between that and Red Valley. A deep cañon lies to the south, which has an east

[1] See Science, Vol. XXI., No. 543, June 30, 1893, p. 355.

course and opens into the Minnekahta Valley. The locality is on the southeast slope, just below the top of the flat-topped spur-ridge and near the abrupt descent into the cañon. From this point northwest to near the crest of the divide the slope is moderate and nearly uniform.

The accompanying sketch-map (Fig. 2) showing the drainage of the region north of the south fork of the Cheyenne river, the Minnekahta Valley, and part of the Red Valley, will enable the reader to understand the general character of the country covered by this reconnaissance.

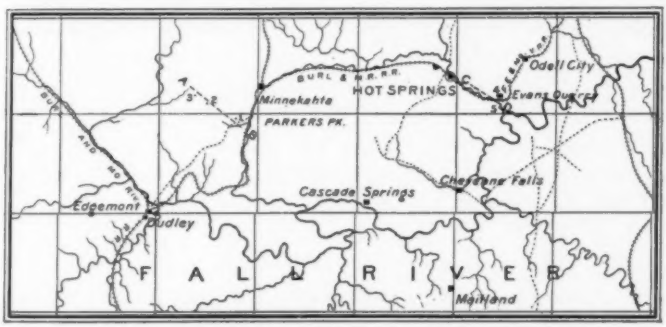


FIG. 2.—Sketch-map of a portion of Fall River County, South Dakota.

A B. Section No. I.
1. Cycad bed.
2. Fossil forest.
3. Plant bed.
C D. Section No. II.
4. Upper leaf bed.
5. Lower leaf bed.

At the foot of this crest on the same (southeast) side, and about one and a half miles northwest of the cycad locality, occurs an extensive fossil forest. The wood is all completely silicified, and consists of prostrate trunks of various sizes and lengths and an abundance of smaller fragments, many of which are scattered about on the sloping plain a long distance below the actual horizon at which they were petrified. At that horizon many still remained apparently undisturbed, and in one place a trunk eight inches in diameter was seen projecting several feet from beneath the massive sandstone ledge. To the south of this point is a

saddle, beyond which the crest of the divide is lower, and here the forest is seen to the best advantage. The most prominent object is an immense trunk, thirty inches in diameter and twenty feet long, lying where it fell at no very remote date, having broken from its roots at the surface of the ground, leaving portions of the stump still exposed. The entire root could probably be exhumed. About the present trunk the lines of splinters and smaller fragments clearly indicate the character of its branches and show that these branches remained attached at the time it fell. A considerable amount of silicified wood occurs also at the same locality as the cycads, obviously preserved by the same influences that preserved the latter. The slope from the fossil forest to the cycad bed is about the same as the dip of the strata. It is therefore probable that both occur approximately at the same horizon. The whole of this region, including the entire crest of the divide and extending to the bottom of the cañon below the cycad bed and far to the southeast, consists of the series of sandstones that have been treated in the Black Hills report as the "Dakota Group."

The great improbability that the cycads could have lived in the Dakota period, or Upper Cretaceous, led us to undertake an investigation of these rocks with a view to the possible discovery of additional evidence of their age. No other fossil remains than the wood and cycad trunks could be found in the immediate vicinity or anywhere on the outer slope of the Cretaceous rim. The crest above the fossil forest consists of harder sandstones, chiefly massive, which may be traced far around the Hills, and which form the upper part of the abrupt escarpment above the soft Jurassic and Red Beds. Passing over this to the northwest we descended into the first lateral cañon entering Red Valley from the northeast. The Jurassic is passed through and the Red Beds fairly entered in the descent. Fifty to seventy-five feet above the Jurassic contact and 175 to 200 feet below the summit of the crest, argillaceous shales with some carbonaceous matter occur interstratified with the sandstones, and at this level, partly in the shales and partly in the rocks, a few fos-

sil plants were found and a small collection made. They bore no resemblance whatever to the flora of the Dakota Group, but consisted chiefly of ferns with a few coniferous twigs and possibly cycadean remains. In short the flora, so far as I could judge, was rather that of the Lower Cretaceous.

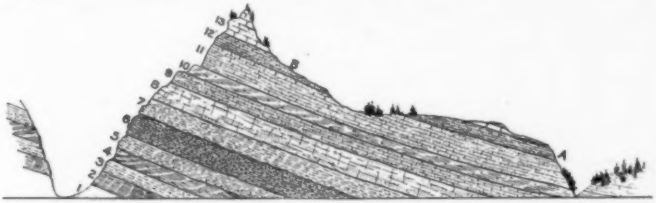


FIG. 3.—Section across the divide between Red Valley and Minnekahta Creek.

1. Red Beds.
2–7. Jurassic.
9. Plant Bed.
12. A, Cycad Bed. B, Fossil Forest.
13. Equivalent of Quarry Sandstone in Section No. II.

The entire section, from the Red Beds at the bottom of the cañon to the summit of the crest forming the divide, was carefully measured, the position of the fossil forest bed, the cycad bed, and the plant bed, fixed as nearly as the circumstances would permit, and all the variations in the nature of the strata indicated. The section, as determined on the spot, is as follows:

SECTION NO. I.

Dakota of Newton. 275 Feet.

13.	Massive pinkish sandstone approaching a quartzite locally	75 feet
12.	Grayish white sandstone with silicified wood and cycads	30 feet
11.	Pinkish and yellowish soft sandstone	75 feet
10.	Clays with indications of coal	20 feet
9.	Soft pink and gray sandstone with ferns and other plants	25 feet
8.	Reddish, pinkish, and yellowish brown massive cross-bedded sandstone	50 feet

Jurassic. 220 Feet.

7.	Olive gray clay and sandstone shales	50 feet
6.	Light red soft sandstone	60 feet
5.	Olive gray clays and gray sandstone shales	40 feet
4.	Olive drab clay	20 feet
3.	Yellow sandstone shales	20 feet
2.	Olive drab clay	30 feet

Red Beds (Trias).

1.	Red marls, conformably exposed at bottom of cañon	20 feet

This section may be represented diagrammatically in Fig. 3.

The Minnekahta Creek, or this southern fork of it, after flowing north through the Cretaceous, enters the Red Beds a little south of the Minnekahta Station, after which it bends to the eastward and follows the strike to Hot Springs. Below this point it takes a southeasterly course, and soon reënters the Cretaceous, cutting entirely through the sandstone and entering the dark Fort Benton Clays a short distance below the cataract at the electric light plant nearly five miles from Hot Springs at Evans Siding. Evans Quarry is just above this point on the left bank. At the last named place Professor Jenney had formerly obtained dicotyledonous leaves, and it was his impression that these might have come from near the horizon of the cycad bed. This region presents an admirable opportunity for measuring a section of the Cretaceous, which it was very desirable to do for comparison with the one last given.

The distance at the bottom of the valley from the Jurassic contact to the Fort Benton is about three miles, and the dip, as the section shows, is over 100 feet to the mile. The quarry is about one-half mile from the point where the sandstones pass under the Fort Benton shales. It has a thickness in workable stone of about 60 feet, and is immediately capped by 40 or 50 feet of softer material. It dips very rapidly to the southeast so as to come down to the stream at the electric light plant, and constitute the rock over which the cataract flows and through which the water has here worn deep longitudinal grooves. Immediately over these rocks and resting upon them there is a bed some six or eight feet in thickness of dark clay and argillaceous shales with carbonaceous matter and some impure coal. In this bed was found a great abundance of more or less comminuted vegetable matter, with short fragments of culms or reed-like plants not determinable. There also occurred in certain of the shales a few tolerably well preserved dicotyledonous leaves, some of which are determinable. They were at least sufficient to indicate with practical certainty that this stratum belongs to the Dakota Group of Meek and Hayden (No. 1). A small collection was made at this point, viz., at the cataract

over the hard sandstones on the right bank of the stream above the electric light plant (5, Fig. 2).

This bed was easily followed to the quarry, where it constitutes the overlying mass which it is necessary to remove in order to uncover the workable sandstone below. At this point the bed also contains layers of soft white sandstone more or less massive. Large blocks of this had been thrown down and lay strewn at the foot of the quarry. On the surfaces of these and more or less scattered through their mass were impressions of dicotyledonous leaves of Dakota types. The shales were also found in places above the quarry, and some of these yielded very good specimens (4, Fig. 2).

The massive sandstone of the quarry is entirely barren so far as could be ascertained, and no fossils were found at any point lower than the bed that overlies it. For a long distance on both sides of the cañon it forms the crest of the ridge, presenting a more or less abrupt escarpment of from 25 to 75 feet. Below it, higher up the stream, beds of softer sandstone, argillaceous shales, and carbonaceous layers with impure coal seams, all highly charged with gypsum, come down to the bed of the stream, and are finally seen resting upon the Jurassic clays, which in turn overlie the Red Beds. Some distance below Hot Springs the Cretaceous can be seen at the summit of the cliffs, with the whole thickness of the Jurassic below them and the Red Beds at the base. At and about Hot Springs there are some heavy beds of conglomerate about which little seems to be known.

The following is the Cretaceous section as measured:

SECTION NO. II.

Fort Benton.

11. Grayish black clays with layers of ferruginous concretions, extending to the south Fork of the Cheyenne River—contact conformable.

Dakota of Newton. 339 Feet.

10. Pink sandstone, mostly thin-bedded, with ripple-marks and fucoid-like impressions ..... 30 feet
9. Soft black shales with traces of carbonized plant remains and some fragments of fossil wood ..... 15 feet
8. Pink and gray sandstone ..... 30 feet

7. Clay shales and sandstones, the latter sometimes white, all plant bearing, much comminuted vegetable matter, matted beds of swamp plants, and well-preserved dicotyledonous leaves of Dakota types, determinable... 10 feet
6. Black clay full of carbonaceous matter, with locally six inches of impure coal ..... 4 feet
5. Quarry sandstone, massive, light pink, soft, weathering iron-brown..... 60 feet
4. Soft yellowish and reddish sandstones ..... 100 feet
3. Drab-colored clays with carbonized vegetable matter and gypsum crystals, interbedded with yellow sandstones ..... 30 feet
2. Soft yellow and reddish sandstones with some clay layers ..... 60 feet

Jurassic.

1. Olive gray, drab or bluish clays with reddish and yellowish sandstones, to base.....

This section may be represented diagrammatically as follows:

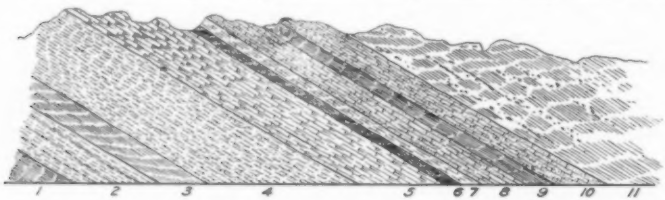


FIG. 4.—Section through Minnekahta Cañon.

1. Jurassic.
3. Equivalent of plant bed in Section No. I.
4. (Upper portion). Equivalent of cycad bed in Section No. I.
5. Quarry sandstone.
7. Dakota leaf bed.
11. Fort Benton.

It will be seen by a comparison of these sections that they are in substantial agreement, although no effort was made to make them so. The crest of the divide in section I represents the Quarry sandstone of section II, which was probably considerably thicker at this point, fifteen feet more being found, exclusive of erosion, but these rocks were often much harder in section I, and no quartzitic rocks were seen in the quarry. On account of the debris thrown down from the quarry and other obstructions, it was not possible to examine the next member below with as much care as was desirable in view of the fact that it seems to be the equivalent of the cycad and fossil forest horizon of section

I; *i. e.*, No. 12 of section I corresponds to the upper 30 feet of No. 4, section II.

At Minnekahta Station, in an ornamental heap of various minerals and rocks from the Black Hills, there were a number of fragments of cycads and fossil wood. We were told that these came from a ridge two miles to the southeast of the station that rises above the Red Beds and shows at its base low buttes and a considerable thickness of Jurassic. This was not visited, but it was evident that the summit of this ridge was formed by the hard sandstone No. 1 of section I (No. 5 of section II), which is continuous to Evans Quarry. The position of the cycad and fossil forest bed here is doubtless the same as on the opposite side of the valley where it was studied.

The occurrence of two other specimens of cycadean trunks, though apparently belonging to a different species, in the same general horizon on the east side of the Black Hills, and of silicified wood in the northern districts, seems to indicate that the same relations obtain on all sides, and this will probably be found to be the case.

The fossil plants of the lower horizon were sent to Professor Fontaine for determination, and the following extracts from his report upon them will show that my interpretation of their significance at the time of their discovery was for all practical purposes correct.

"The best preserved fragments are scattered leaflets, and the summits of the ultimate pinnæ of ferns, which are the parts of those plants which have great value in fixing species. The following are the plants:

"1. The summits of ultimate pinnæ of a fern, which is decidedly like *Asplenium Dicksonianum* Heer, from the Kome beds of Greenland. It has also something of the character of the widely diffused Potomac plant, *Thyrsopteris rarinervis*, but is, I think, nearer Heer's plant.

"2. Some ends of the ultimate pinnæ of a small fern with the facies of a Gleichenia. This is nearest to Heer's *Gleichenia Zippei*, from the same Kome beds, but the pinnules are rather more acute

than most of those of that plant, and indicate that those on this plant, lower down, are somewhat larger than those of *G. Zippei*. The form is also something like *Aspidium heterophyllum*, of the Potomac, but seems to be smaller and more delicate. It may however be the same.

"3. The most common fossils are fragments of detached leaflets and one entire leaflet, of a plant which is strikingly like a Neuropteris of the coal measures (*N. flexuosa*). I am pretty sure, however, that it is a Glossozamites, a form of cycad that has leaflets which, in form and nervation, closely resemble Neuropteris. This, if a Glossozamites, has leaflets proportionately broader and shorter than any known to me, and it is probably new.

"4. There are a number of imprints left by organisms which in shape, dimensions, etc., would agree with fragments of the leaves of Pinus, or of Leptostrobus, but as nothing of the nervation is shown, it is not possible to say which they are. Some of the imprints are too deep and open, apparently, to have been formed by leaves. They seem to have been straight, slender stems.

"It will be seen from this account that the plants, so far as one can judge from such imperfect material, indicate a lower Cretaceous and Neocomian age, with rather more resemblance to the Kome than Potomac phase or grouping, but it is by no means certain that the Potomac grouping is not nearest to that here shown."

Thin sections of some of the silicified wood have been made and microscopically studied by Professor F. H. Knowlton. He reports the results as follows:

"The structure of this wood is very finely preserved, and a glance suffices to show that it possesses the Araucarian type and represents, with little question, an undescribed species of the genus Araucarioxylon. The wood-cells are provided with two rows of alternating hexagonal pores on the radial walls, which nearly, or in some cases, quite cover the walls. The medullary rays are composed of a single layer of thin, short cells, each of which is covered on the radial side with numerous fine dots or punctations. The rays are from one to bout twenty cells high, the average number being perhaps eight or ten. A

large number are composed of only one or two cells. The annual rings are rather indistinct, yet can be made out.

"As far as I now know, only two species of Araucarioxylon have been described from the United States, *A. Arizonicum* Kn., from the Triassic or Lower Jurassic of New Mexico and Arizona, and *A. Virginianum* Kn., supposed at first to belong to the Potomac formation, but now known to be from the Trias of Virginia. These species differ markedly from the one under discussion. With the *A. Arizonicum* it has almost no points in common, while it differs from the *A. Virginianum* in important particulars."

The only sections of the fossil wood that have yet been made were cut from a specimen taken from the cycad bed proper and not from the principal fossil forest, but it often happens that only one species can be found in such a forest. It is therefore probable that the same structure would be shown by the other specimens. I confess to a little surprise at finding that this structure represents the Araucarian rather than the Sequoian type of conifers, since, in the east at least, these two types characterize the Trias and Potomac respectively, no Araucarian specimens having been found in the Potomac and no Sequoian specimens in the Trias. And generally the Araucarian type is more ancient. This evidence therefore points to a lower instead of a higher horizon.

I have made a somewhat careful study of the specimens from the plant bed above Evans Quarry, and have asked Professor Knowlton to assist me, his experience in recently editing Lesquereux's Flora of the Dakota Group having familiarized him with the forms of that age. The result of our joint investigation may be summed up as follows:

The specimens are few and fragmentary, and the only species that can be even approximately determined are:

Asplenium Dicksonianum Heer.
Quercus Wardiana Lx.?
Lindera venusta Lx.
Aralia Towneri Lx.?
Virbunites Evansanus n. sp.

The first of these was described by Heer from the Kome beds of Greenland (Gault or Urgonian), but it also occurs in the Atane beds, which are correlated with the Cenomanian and have been supposed to be nearly equivalent to the Dakota Group. It has been found in the Kootanie deposits of British America, in a supposed Neocomian deposit at Cape Lisbourne, Alaska, and in the Amboy Clays at Woodbridge, New Jersey. It is also one of the few ferns that have been found in the Dakota Group, where, however, it is rare. Its evidence, therefore, considered by itself, would be to put even this uppermost deposit in the Lower Cretaceous, but this is overcome by that of the remaining forms. The specimens are the best in the collection, good and characteristic, leaving no doubt on the score of identity.

Quercus Wardiana Lx., is an exclusively Dakota form, but the specimens are too imperfect to make the determination sure.

Lindera venusta Lx., is a characteristic Dakota species, and one of the specimens leaves no doubt as to identity.

Aralia Towneri Lx., is also confined to the Dakota Group, but the specimens, though tolerably good, do not exactly agree, the lobes being too short. They most resemble the specimen figured by Lesquereux in his Flora of the Dakota Group, pl. xxxi, fig. 3, which he doubtfully refers to *Sterculia Snowii* Lx., but which does not at all resemble the type specimens of that species, and probably belongs to *Aralia Towneri*.

The leaf which I name *Viburnites Evansanus*[1] is one of the best preserved in the collection, but it differs specifically from all the forms known to me. It is clearly of the type of *Viburnites crassus* Lx., and *V. Masoni* Lx., of the Dakota Group (Fl. Dak. Gr., pp. 124, 125; pl. xlv), but is longer in proportion to its width with a larger number of secondary nerves, which are irregularly disposed, the angle differing on the two sides of the midrib, as do also their number and proximity. The branching is strictly dichotomous and the finer nervation is distinct. The margin is only preserved near the summit, but here it is that of *V. crassus*.

[1] For Mr. Fred. Evans, proprietor of Evans Quarry, founder and leading citizen of Hot Springs, who greatly aided and facilitated the expedition.

It thus appears that the flora of the beds above Evans Quarry is distinctly that of the Dakota Group, while all the plants found below that horizon as distinctly indicate a Lower Cretaceous age. The force of this evidence is to my mind irresistible, and it is safe to predict that if any other paleontological evidence is ever found it will confirm this conclusion. The question still remains as to where the dividing line is to be drawn. Between the cycad and fossil wood horizon and that of the Dakota leaves there are some hundred feet of sandstones and shales. Sixty to seventy-five feet of this consists of the massive or heavy-bedded building stone, which in places becomes flinty and very hard. As the thin shaly layer which separates this from the leaf bed may be safely put with the latter into the Dakota proper, and there seems no reason for separating the similarly constituted layer that intervenes between the cycad horizon and the base of the sandstone from the one upon which it rests, the question is narrowed down to that of the position of the quarry sandstone. That question I will leave to the stratigraphical geologists.

As to where in the Lower Cretaceous series the basal portion of the Cretaceous rim of the Black Hills should be located, it can only be said that the cycadean trunks elsewhere found in North America have all come from well down in that series or else from the Upper Trias. Leaving the latter cases out of the account we have the Maryland specimens and the one from Kansas. It was long supposed that the Maryland specimens were derived from the Iron Ore Clays, which were referred by McGee and Fontaine to an "Upper Clay Member." This is now known not to be the case, and it has been demonstrated that the cycads occur in the basal sands at the same horizon as the Sequoian trunks, and probably the same as the Rappahannock freestone, which has yielded more fossil plants than any other horizon. Whether this is the same horizon as that of the James river, where cycads and conifers prevail and no dicotyledonous leaves have been found, or a somewhat higher one, need not now be discussed, as the whole subject will soon be thoroughly presented along with the evidence. Certain it is that the Potomac

cycads belong to the lower part of that formation. The Kansas specimen is confidently referred by Professor Cragin to the Trinity Group of the Comanche series of Hill, which forms the lowest division of that series. Professor Hill is disposed to accept this conclusion, and Professor Prosser of Washburn College, Topeka, sees no reason to doubt its accuracy.

The other plants, as has been seen, occur about one hundred feet below the cycad bed. Professor Fontaine's report above quoted places their significance in its true light and leaves little to add. The occurrence of *Asplenium Dicksonianum* shows simply that this common form persisted in the same area through a long period. But this it was already known to do. Should it, however, prove to be the *Thyrsopteris rarinervis* Font., it would be a characteristic lower Potomac species.

The forms that Professor Fontaine refers to Glossozamites argue entirely for a Lower Cretaceous or even earlier age. Eight species of that genus are known, ranging from the Upper Trias to the Urgonian. Some are from the Lias, but most of them are found in the Wealden and Neocomian. They had a wide geographical range, occurring in Greenland (Kome beds), India (Damuda series), and in various parts of Europe. One species, *G. distans*, is from the lower Potomac of Fredericksburg, Virginia.

Gleichenia Zippei (Corda) Heer was first described by Corda, who referred it to Pecopteris, from the Gosau formation of Bohemia, supposed to be above the Cenomanian. It has since been found in the true Cenomanian of Bohemia and in the Quadersandstein of Germany. Heer found it in all the Cretaceous beds of Greenland (Kome, Atane, Patoot), also in the Cretaceous of Spitzbergen. Newberry detected it in the Amboy Clays. It varies considerably, and the name may include more than one species. Fontaine compares the Black Hills specimens only with Heer's Kome forms, and is not certain that they may not rather represent his own *Aspidium heterophyllum* from the Lower Potomac of Fredericksburg. The evidence afforded by this species, therefore, is not strong, but it certainly does not occur in the Dakota Group elsewhere so far as known.

Leaves of Pinus and Leptostrobus occur quite frequently in the Potomac formation in Virginia, Alabama and New Jersey, but have never been found in the Dakota Group. So far, therefore, as these forms from the Black Hills go they favor the view that the bed in which they occur is Lower Cretaceous.

The chief argument from the plants is that they were all of humble types, no dicotyledonous leaves occurring among them. The force of this argument may be appreciated when it is remembered that the flora of the Dakota Group, one of the richest fossil floras of the world, consists, as now published, of 460 species, of which 429 are Dicotyledons. There are only 6 ferns, 12 cycads, 15 conifers and 8 monocotyledons. The cycads are only known by fragments of fronds or pinnæ, and a few doubtful fruits. The chances are hundreds to one that any plant bed of that age will contain dicotyledonous leaves in profusion, and the lower forms very sparingly, if at all. This was found to be the case at the real Dakota plant bed above Evans Quarry. Only one fern was obtained, while leaves were abundant though difficult to secure entire with the insufficient appliances with which we were provided.

A closing word on the bearing of these facts upon the Lower Cretaceous of North America may be permitted. It would seem probable that a considerable portion of the deposits underlying the marine Cretaceous of the Rocky Mountain region which have heretofore been referred to the Dakota Group on purely stratigraphical evidence may really be much older. When in 1883 I descended the Missouri River from the mouth of Sun River to Bismarck, most of the way in a "mackinaw," and in company with Dr. C. A. White, that able geologist was of the opinion that the rocks at the Great Falls of the Missouri belonged to the Dakota Group. They were seen distinctly passing under the Fort Benton shales below, and there were no more indications of a division line at any point in the series than Professor Newton found in the same section of the Black Hills. As no Cretaceous older than the Dakota Group was at that time supposed to exist in that region, it was natural to refer all below the Fort Benton to

that group. But when a rich plant bed was at length discovered at Great Falls it was found to belong to the Kootanie group of Dawson, as developed in regions nearly north of this point. Here then is another series in which the dividing line between the Upper and Lower Cretaceous has to be found.

It would, perhaps, be rash to predict that like conditions will be found to prevail at most points along the slopes of the Rocky Mountains, but the facts are sufficient to constitute a good working hypothesis, and a systematic search at various points in the rocks that overlie the Red Beds and the Jurassic wherever these occur may result in further valuable discoveries. One additional fact that points in this direction may be noted. There was picked up on the surface within the Laramie terrane at Golden, Colorado, a segment of a small cycadean trunk which Lesquereux called *Zamiostrobus mirabilis*, but which has been sent to Count Solms-Laubach, Professor of Botany at the University of Strasburg, and the leading authority on the subject, and pronounced by him to be a trunk and not a cone (as, indeed I had myself previously stated),[1] referable to the genus Cycadeoidea. This region, as most geologists know, lies at the foot of the Front Range, and marine Cretaceous passes under the Laramie at Golden. The several members of the Cretaceous, in descending order, would naturally be found in passing up the adjacent slope, and if a horizon yielding cycad trunks occurs here it would be very natural that some of these cylindrical trunks should roll down the steep escarpment and be arrested on the plain below where this specimen was found. This explanation is far more probable than that this form could have grown in Laramie time, though no one can say that this is impossible, especially as the specimen is a diminutive one and may represent the degenerate descendants of the robust forms of the Lower Cretaceous.

Whatever future consequences may grow out of the discoveries recorded in this paper they at least, in and of themselves, constitute a fresh contribution to our rapidly growing knowledge of one of the hitherto least known periods of North American geology, to wit, the Lower Cretaceous.

LESTER F. WARD.

[1] Science, Vol. III., p. 533 (1884).

ON DIPLOGRAPTIDÆ, LAPWORTH.[1]

In the fall of 1888, H. Munthe brought from Bornholm a piece of Baltic sea limestone[2] [Ostseekalk] with graptolites, which he kindly gave me, as I was at work on the Silurian region of the Bothnian sea. From this piece, half the size of one's fist, I have obtained, by the aid of muriatic acid and vinegar, several hundred pieces of a *Diplograptus*. As this compact limestone is excellently qualified to preserve the very finest details, the fragments, which consist mainly of proximal-ends and sciculæ, furnish excellent material for the examination of the inner organization of this particular *Diplograptus*.

These remains are of a half-carbonized, chitinous substance, and after separation were dark brown and almost opaque, therefore I treated them with Schulze's maceration medium by which their color was changed to light brown or yellow. After careful washing with water, they were further treated with alcohol and oil of cloves, and were then preserved in the ordinary way in Canada balsam.

According to the present acceptation, as recorded in general hand-books of paleontology,[3] and in the main the same as that given by Lapworth[4] as early as 1873, the family *Diplograptidæ*, Lapw., is characterized as follows: Hydrozoma, consisting of two branches united dorsally, between which the scicula is imbedded, its broadest portion forming the proximal end of the hydrozoma.

[1] Extract from Bulletin of the Geological Institute of Upsala, Vol. I, No. 2, 1893. Translated from the German by CHARLES SCHUCHERT.

[2] C. WIMAN: Ueber das Silurgebiet des Bottnischen Meeres, I, p. 73, Bull. Geol. Instit., of Upsala, Vol. I, No. 1, 1893.

[3] K. A. ZITTEL: Handbuch der Palæontologie, Abtheilung I, Band I, 1876-1880. H. A. NICHOLSON and R. LYDEKKER: A Manual of Palæontology for the use of students, Part I, Third Edition, 1889.

[4] Notes on British Graptolites and their Allies, I.—On an improved Classification of the *Rhabdopora*, Parts I and II, Geol. Mag., Vol. X, pp. 500, 555, 1873.

Since in fact the graptolites are generally compressed and altered into a metallic sulphide, or are otherwise poorly preserved, and as this was also largely the case with the material examined by Lapworth, the genus *Diplograptus* was referred to the *Diprionidæ*, mainly by a comparison with other forms, particularly *Didymograptus* and *Dicranograptus*.

In 1876, Lapworth[1] described two species of a new genus, *Dimorphograptus*, and, because of these, doubted the existence of any diprionidian forms. The proper view, he believed, was that the scicula in all graptolites develops but one bud. This view (an opinion founded on fact) that a monoprionidian scicula which at first gives off a monograptus-like hydrosoma could really give origin to a complete diplograptus-like distal end, has in later literature never been considered, but the older idea has been persistently retained to the present time.

The Scicula. In the present material, this is represented by 168 specimens, and of these 85 are separate. The form of the scicula is given in Pl. II., fig. 1-5 and 7-9. It is divisible into two essentially different parts, the distal one having a very thin and transparent wall, while the proximal is thicker and less transparent. Along the wall of the distal part are longitudinal thickenings or lines which branch and anastomose basally, and are lost near the boundary with the proximal portion. They unite, however, in the point of the scicula, and form the distal portion of the virgula to which I will again refer. Between the two parts of the scicula there is no septum.

In the proximal part of the scicula can be seen closely arranged diagonal lines, which I regard as growth lines. These have the same appearance as the often described thecal lines, differing only in the fact, that at a certain distance from the virgula, they gradually bend downward to join it at a sharp angle. In the very oldest part of the proximal portion of the scicula, the lines round regularly (Pl. II., fig. 1), since the virgula, when these were forming, was not yet present. Very soon, however, they begin to exhibit a slight downward bending, and this increases

[1] On Scottish *Monograptidæ*. Geol. Mag., Decade II, Vol. III, p. 544, 1876.

line for line until the virgula begins to show, and practically absorbs the lines. The angle at which the lines and the virgula unite diminishes with age. The mature scicula is provided with three spines at its aperture, one of which is the cylindrical virgula. The other two are flat, and should probably be termed lobes. They have that appearance, as shown in figure 5, and are situated opposite the virgula on each side of a shallow emargination of the aperture, joined by a slight swelling of the border of the indentation.

The form and completion of the aperture gives the scicula a particularly conspicuous bilateral symmetry, on account of which the animal at this stage recalls a bryozoan rather than a modern hydroid polyp.

The Theca. Before the scicula has matured, there forms, at the point illustrated in Pl. II., fig. 4, the beginning of a second tube, which is also provided with growth lines. The circular perforation by which it communicates with the cavity of the scicula has been observed in forty-one examples. This opening is not produced by absorption of the wall as shown by the slight irregularity of the scicular growth lines at the origin of the second tube (Pl. II., fig. 4). This tube does not develop into a general canal or similar part, but forms the first theca. Then from this one chamber of habitation there simply develops a second.

The first theca (Pl. II., figs. 4, 5) at once leans closely on the scicula, widens very rapidly, approaches toward the virgula, and in bending around the scicula passes it, so that the theca comes to lie on the back (dorsal) side[1] of the scicula, and eventually both increase at an equal rate towards the proximal end. The growth lines of the first theca like those of the scicula, although in a less degree, are also drawn along, so to speak, by the virgula. As soon as the theca, which clings closely to the virgula, has grown a little further than the scicula towards the proximal end, it again changes its direction, and bends outward and eventually upwards. Where it begins to grow upwards, it gives off from one to three spines in succession, which start with a slight emar-

[1] I have named that side the front which in figures 4 and 7, faces the observer.

gination of the wall, and appear to develop like the spines of mollusks. In one example (Pl. II., fig. 6), two approximate spines are joined by a thin skin. Therefore there are from four to six spines on the proximal end of this *Diplograptus*.

A second large hole opens on the first theca towards the front side (Pl. II., fig. 4). On the back side (Pl. II., fig. 5), the lines are disposed parallel with its margin; on the front, however, they converge. From this opening comes the second theca (Pl. II., fig. 7), on the right side in front of the scicula. Shortly after it has left the first theca, the turning of the hydrosoma must have taken place; *i. e.*, both thecæ now begin to grow in an opposite direction and thereby change the direction of the aperture towards the distal end. Further scicula growth probably ceases at this stage of development. The newly-formed theca fastens itself to the forward spine on the right side of the scicula.

The second theca hardly has left the first when it gives origin to the third, which also lies on the first, and is therefore situated on the left side. The pore uniting the third theca with the second is situated a little more proximally than that which joins the second with the first. The earliest budding of the third theca, therefore, occurs between the origin of the second and the turning of the hydrosoma. Its lower part fills the space in the bend of the first theca (Pl. II., fig. 8).

In my material occur many specimens having only the scicula, the first two thecæ, and the proximal portion of the third. If such an example were pressed flat without relief, and changed into pyrite, it would be recognized as a scicula having two buds with a common canal. The third theca increases only at the distal end. From it, the fourth theca takes its origin, and is situated in front of the scicula on the right side of the hydrosoma (Pl. II., fig. 8).

Even if the openings between the first and second and the second and third thecæ were not apparent, but only the origin of the first theca from the scicula and the fourth from the third were observed, the following law for the formation of the thecæ could be deduced: Each theca has its origin in the next on the

opposite side of the hydrosoma. The alternating of the thecæ, therefore, is not only governed by the greater space attainable, but by the age and origin of the thecæ as well. In certain respects this law is also true for the scicula which may be regarded, if desirable, as the primary theca.

The growth lines meet on the outer edge of the hydrosoma in such a way as to produce a zig-zag line (Pl. II., fig. 7). This is probably produced by the same cause as the marking of the lobes of the scicula. Analogous to these, also, are the well-known paired spines of the thecal apertures of certain diplograptids, which are likewise an expression of the bilateral symmetry of the thecæ.

The partition wall between two adjoining or opposite thecæ is naturally double, and exhibits a slight thickening on the proximal inner edge.

The angle between the median line of the hydrosoma and the double partitions of the thecæ is greater in the distal portion, (25°-30°) than in the proximal, where it is occasionally zero.

An examination of figures 8 and 9 shows that the scicula originally lies outside of the hydrosoma, except for the loose adherence of the thecæ, being united to it only at the termination of the first theca. Nevertheless the earliest thecæ are indented on the dorsal side and partly enclosing the scicula, so that it appears to lie in a depression of the outside of the hydrosoma. The thecæ extend more and more over the scicula until the central space is nearly transformed into a tube encircling the scicula, and when the fifth theca, *i. e.*, the third on the same side as the first, finally opens, the scicula then disappears into the hydrosoma (Pl. II., fig. 9). The place where the scicula comes in contact with the perforated wall of the hydrosoma lies beneath the boundary between the two parts of the scicula (Pl. II., fig. 9).

The Virgula. As the virgula has been observed to occur within, and protrude from, both ends of the hydrosoma, it has been naturally concluded that the virgula passed without interruption through the entire hydrosoma. This, however, is not the case (Pl. II., figs. 1-3). The origin of that portion of the virgula which lies in the left wall of the proximal part of the

scicula has been already described. This part like the scicula grows towards the proximal end. The distal portion of the virgula does not begin to develop until the scicula has been taken into the hydrosoma. It is likewise stouter the further it is removed from the point of the scicula. As it has its origin in the union of the longitudinal lines of the distal portion of the scicula, it appears very probable that the entire distal part of the scicula, also, first had its inception when the scicula is taken into the hydrosoma. Accordingly, the scicula, when it was yet free, would have been either open on the distal end or it had a very thin wall which disappeared later. The first shell-layer, therefore, was a small simple ring.

Here and there, quite irregularly, the virgula fastens itself to the above-mentioned swellings on the proximal ends of the thecal partitions (Pl. II., figs. 11-12). In figure 10, it is entirely free. In diagnoses of diplograptids, it is often mentioned that the virgula extends beyond the distal end. This need not be accidental in a species of this nature, since in forms where the virgula is not fastened to the diagonal swellings, it has a greater chance of being preserved, even if the periderm is broken away. If the virgula is regularly attached to every partition, it can only become protruding under very favorable circumstances. In this species, I did not see the virgula protruding.

A common canal as progenitor for all thecæ does not exist. The partition walls between the thecæ, moreover, join so closely on the center of the hydrosoma that the virgula hardly has sufficient space to straighten itself.

A longitudinal septum is not present.

In summing up the results of my investigations, the following points are shown :

1. The scicula consists of two parts, is basally open, and bilaterally symmetrical.

2. From the scicula there sprouts but *one* bud. This *Diplograptus* is therefore monoprionidian.

3. This bud does not develop into a canal, but into a theca.

4. Each theca comes forth from the next more proximally

situated theca of the opposite side, and not from a common canal.

5. The hydrozoma including the virgula has grown in two opposite directions.

6. The scicula is not imbedded between two branches grown together, but is free originally, and later is incorporated within the periderm.

7. The virgula is not double, and has two quite distinct phases of development.

8. To the virgula are occasionally attached the bases of the thecal partitions.

9. A common canal as progenitor of the thecæ does not exist.

10. A double longitudinal septum is not present.

It is not now my intention to assert that this organization is repeated in all the representatives of the family *Diplograptidæ*, for so little of their internal structure is yet known, they may have a collection of remotely related forms with thecæ arranged in two rows, but since this family is entirely or in the main a natural one, the deviation from the general plan of structure cannot be very great.

Eight days after I had announced the above before the geological section of the Student's Natural History Society, and after I had nearly finished writing it, I received from S. L. Tornquist a copy of his work "Observations on the structure of some *Diprionidæ*." Särtryck af Kongl. Fysiografiska Sälls Kapets Handlingar. Ny följd 1892-3, Bd. 4, Lund, 1893. Lund Univ. Årsskrift, tom XXIX.

The "connecting canal," which, according to Tornquist, unites the scicula with the "common cavity of the rhabdosoma," is that part of the first theca which grows downwards. The proximal end of *Climacograptus scalaris*, Lin., figs. 7–15, and 18-20, *C. internexus*, Tqt., fig. 25, *Diplograptus palmeus*, Barr., figs, 29, 33–35, and *Cephalograptus cometa*, Gein., figs. 39–41, show the identical structure which I have just described. The groove illustrated in figure 17 and mentioned on page 6 as "a narrow longitudinal groove as to the nature of which I am not

able as yet to offer any satisfactory explanation," can be, since it terminates before it reaches the point of the scicula, nothing else than that portion of the virgula which lies in the wall of the scicula.

Tornquist nowhere says that the described species are monoprionidian, but this can be clearly seen in the figures 39-41 of *Cephalograptus cometa*, Gein., and if those just cited are compared with my own, there can be no doubt that the species above mentioned are also monoprionidian.

It is particularly interesting to note that the presence of a longitudinal septum does not depend on the diprionidian character of the *Diplograptidæ* as generally accepted.

EXPLANATION OF PLATE.

The figures have been drawn about twice the size of the scale, with Zeiss and Abbe's drawing apparatus. The shading was obtained by still greater enlargement, and by various accessories to the microscope. The given scale does not apply to figure 10.

Fig. 1. Young scicula; dorsal side. × 37.

Figs. 2-3. Adult scicula; front view. The thecæ are removed. 37–1.

Fig. 4. Form and place of the first theca and the perforation from which the second will come; front view. × 37.

Fig. 5. The same; dorsal view. × 37.

Fig. 6. The first theca with three spines, two of which are united by a thin skin. × 37.

Fig. 7. Form and position of the second and third thecæ; front view. × 37.

Fig. 8. Form and position of the fourth theca and imbedded scicula. × 37.

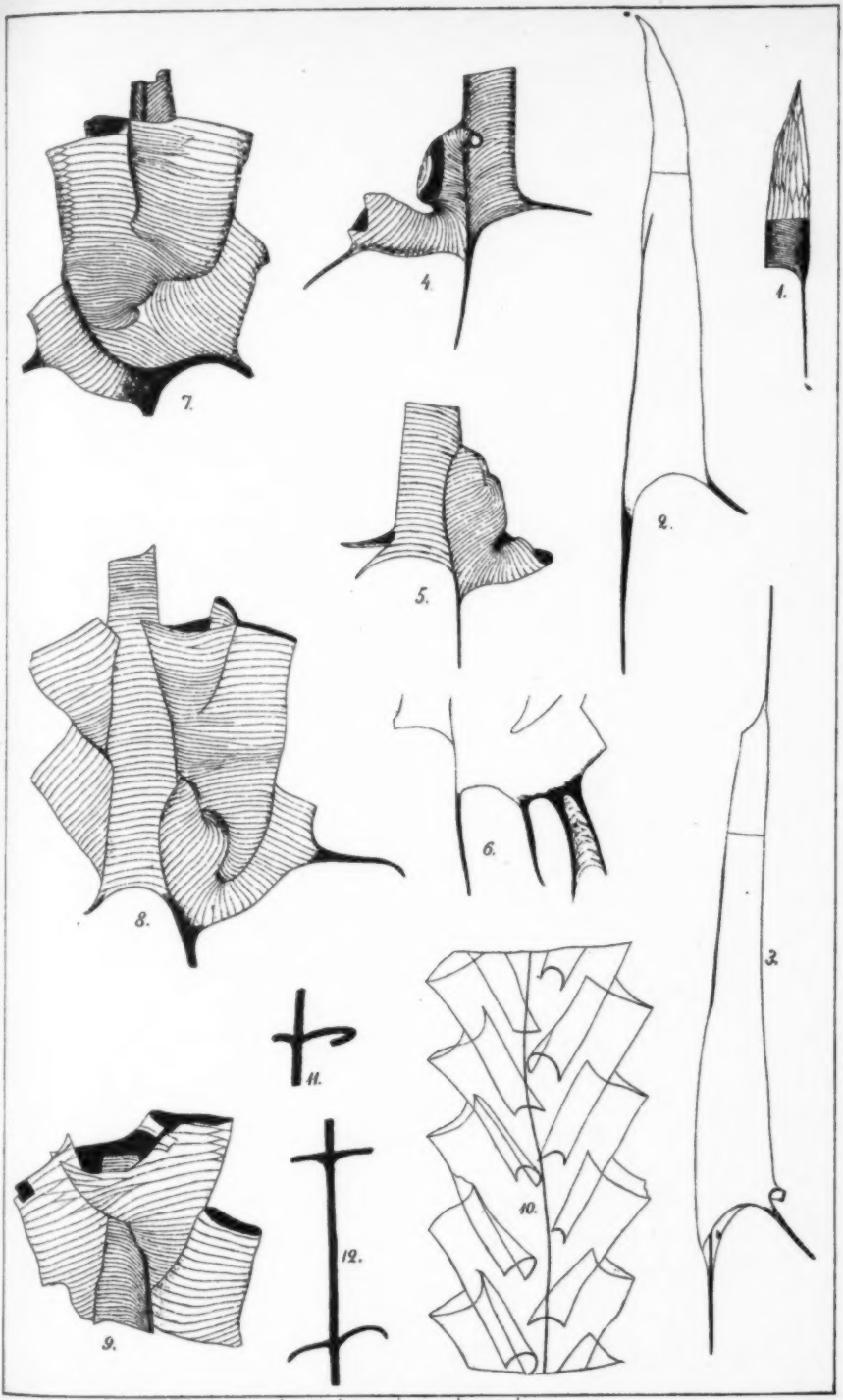
Fig. 9. Incorporation of the scicula in the hydrosoma. × 37.

Fig. 10. Distal portion. The transparency partially made use of. The virgula is wholly free. × 13.

Figs. 11-12. Attachment of the proximal edges of the partitions to the virgula. × 37.

The material is in the collection of the Geological Institute at Upsala.

CARL WIMAN.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GEOLOGICAL SURVEYS IN ALABAMA.

First Survey.

Upon the appointment of Professor Michael Tuomey, in 1847, to the professorship of Geology in the University of Alabama, it was made a part of his duty to spend such portions of his time, not exceeding four months in each year, in exploring the state in connection with his proper department, as the Trustees might consider for the advantage of the state. Professor Tuomey, in accordance with these instructions, began immediately his explorations, and thus the first systematic examination of the geology of Alabama was instituted. Such extracts from his reports to the Trustees upon this work as were considered of general interest, were published from time to time in the newspapers of the city of Tuscaloosa, and in January, 1848, the state legislature made recognition of this effort by appointing Professor Tuomey State Geologist, and requesting him to lay before them the results of his explorations, to be published by the state. Thus was begun the first geological survey of Alabama. From 1848 to 1853 Professor Tuomey continued these explorations at the expense of the University of Alabama, the state having made no appropriation for the purpose, and in 1849 he presented to the legislature his first biennial report, which was published in 1850 by the state. The geological map was not ready, however, for distribution with the report, and appeared separately. When we consider the great number of observations recorded in this volume, and the accuracy with which the limits of the various geological formations were laid down upon the map, after only two years' exploration, in a state about whose geology almost nothing was previously known, we cannot fail to recognize the genius of the man.

In 1854 the legislature passed a law appropriating $10,000 for the support of the Geological Survey, and an additional sum

of $2,500 per annum for the salary of the state geologist. Under this law Professor Tuomey was appointed State Geologist by Governor Winston, resigned his position in the University, and devoted his whole time to the survey till about 1856. During the two years, however, of his service to the state he still kept his office at the University of Alabama, and delivered lectures to some of the classes of that institution. During this time he was assisted by Professor E. Q. Thornton, O. M. Lieber and others, and in 1855 Professor John W. Mallet was appointed Chemist to the survey. The results of the labors of Professor Tuomey and his assistants were brought together by him in a report which was submitted to the legislature in November, 1855, but, by the negligence of the state printers, and for other reasons, the publication of this report was delayed for more than two years. The appropriation for the survey being exhausted, Professor Tuomey resumed his work at the University in 1856, intending to devote his leisure time as before to the survey, and especially to the elaboration of his notes. The summer of 1856 was devoted to field work, but his death occurred the following year 1857, on March 30.

Upon the death of Professor Tuomey, Dr. Mallet undertook the task of editing and bringing out the long delayed report It was found that part of the manuscript had been lost, some of it was incomplete, and thus a large amount of valuable material was lost to the state and to science. In September, 1858, this Second Biennial Report at last appeared, accompanied by another map of the state, more detailed than the first. After the death of Professor Tuomey, in 1857, the survey was discontinued.

From 1868 to 1876 a Commissioner of Industrial Resources was one of the regular officers of the state government, and four small pamphlets were issued from that office, but the Legislature of 1874–5 practically abolished the office by making no appropriation for the salaries of the Commissioner and his Assistant, and in the code of 1876 no provision was made for the continuance of the Bureau.

Second Survey.

First Decade.—In the meantime, upon the reorganization of the University of Alabama, in 1871, after a "reconstruction" régime of five years, the Board of Regents of that institution again took the initiative in re-establishing the Survey by requiring the Professor of Geology to devote as much time in traveling over the state, in making examinations and collections in geology, as would be consistent with his duties at the University.

In pursuance of this ordinance, the present writer, who at that time filled the chair above mentioned in the University, spent a part of his vacation in 1871, at his own expense, in the examination of certain marine Tertiary deposits in Clarke, Washington and Choctaw counties.

The subject of the Geological Survey was brought before the legislature of 1872–3, and an act was passed by them in 1873, reviving the survey, naming Eugene A. Smith, State Geologist, and making an appropriation of $500 per annum for the expenses of the survey, and an additional appropriation of $3,000 for an outfit for chemical laboratory, and traveling and camp equipments. In 1877 a bill was passed making a biennial appropriation of $200 for the purpose of preparing maps and other illustrations for the geological reports. Another special appropriation of $250 was made in 1879 for the same purpose.

During the ten years from 1873 to 1882 inclusive, the writer devoted the greater part of the three months of each summer vacation to geological excursions, receiving no compensation therefor in the way of salary. The actual traveling expenses were, however, defrayed out of the annual appropriation of $500, which also paid the other contingent expenses of the survey. In the summer of 1878 Mr. Henry McCalley, at his own expense, accompanied the writer in the field, and during the following years, from 1879 to 1882, he undertook independent field work, without compensation from the survey beyond the payment of his expenses while in the field. At this time he held the position of Assistant in the Chemical Department of the University, then also under the charge of the present writer. There were other

volunteer assistants during this time; the two whose contributions are to be found in the survey reports being Professor W. C. Stubbs, who made a number of chemical analyses, besides taking part in the field work, and Mr. T. H. Aldrich, who prepared a valuable sketch of the early history of coal mining operations in Alabama, published in the report for 1875.

Publications.—During this period of ten years there were published four annual reports, viz., for 1873, 1874, 1875, and 1876, and three biennial reports, viz., for 1877–8, 1879–80, and 1881–2.

With the exception of the Agricultural report of 1881–2, these were of the nature of preliminary or reconnoissance reports, and they deal chiefly with the economic features of the state. The report for 1873 was a mere statement of the plan of the work proposed. That of 1874 is concerned with the crystalline region, and particularly with the copper-bearing strata. At the time when the examinations were made there, the whole section was greatly interested in the subject of copper, just as now it is interested in gold. A part of the next report, 1875, treated of the same subject, but the greater part of it was devoted to the examination and classification of the Valley formations, of Jones' Valley and the great Coosa Valley region. Professor Tuomey recognized the occurrence in these valleys of the Silurian, Devonian, and Subcarboniferous formations, without undertaking the subdivision of the same, except in the case of the Clinton and Trenton. During the summer of 1875, it was possible for the writer to establish the practical identity of these formations with what had already been so clearly described for Tennessee by Professor Safford, and he established the fact of the existence in Alabama of the Ocoee, Chilhowee, Knox Sandstone, Shale and Dolomite, the Lower and Upper Subcarboniferous with their respective minor divisions. The report for 1875 contained also the sketch of the early history of Coal Mining in Alabama, to which reference has already been made above, and there were also presented the records of the borings by diamond drill in the different parts of the Warrior Field together with an attempt at correlating the same. The report holds also many details of the

occurrence and composition of iron ores and limestones of this district. The report for 1876 continued the examination of the valley regions, and contained a paper on the Alabama fresh water shells by Dr. James Lewis, contributed by Mr. Aldrich.

In 1877–8 attention was turned to the Warrior Coal Field, till then comparatively unknown, and maps were published of Walker, Fayette, Marion, and Winston counties, which were practically underlaid with Coal Measures. Notwithstanding the fact that no coal was mined at that time in all this region, and it was not possible with the means at the disposal of the survey to open the seams so as to show their true value, the publication, especially of these maps, turned the attention of investors to these counties, and the next few years witnessed marvellous developments there.

In 1878–9 a movement was set on foot to secure an appropriation from Congress for the purpose of making navigable the Upper Warrior river to develop the coal seams along its course, and the writer, with Mr. McCalley and Mr. Jos. Squire, ran a line of levels from the forks of the Warrior down to Tuscaloosa, and made special re-examination of the coal seams within available distance from the river. The expense of this survey was borne chiefly by the War Department, but the map and report were published by the survey. In this document the details of the coal seams were given with a much greater degree of fullness than heretofore, together with many facts bearing upon their stratigraphical relations. In this volume was also a continuation by Mr. McCalley of the description of the Tennessee valley, begun the year before by Mr. McCalley and myself; together with the analyses of some 50 specimens of coal from the Warrior field.

In 1880 the writer was requested by Dr. Hilgard to prepare for the Tenth Census a report on Cotton Culture in Alabama and Florida, and in 1883 was published the state report, embracing the results of these observations in Alabama. In addition to the special descriptive matter, this report contains a general discussion of the composition, mode of formation, and properties of

soils and of the changes produced by cultivation. The maps showing the agricultural divisions of the state, and showing the relations between the area cultivated in cotton and the total area, were prepared for the Tenth Census, but the survey had the privilege of using the plates. The other illustrations were prepared by the survey. This report deals in some detail with the agricultural divisions of the state, and contains many analyses of soils and marls, made partly by the Census and partly by the geological survey.

In the case of the two reports last named, advantage was taken of opportunities in which work done by the writer for other organizations could be turned to the direct benefit of the survey, thus securing much fuller reports and better illustrations than would have been at all possible with the survey funds alone.

Cost.—The printing of these reports was paid for out of the general printing fund of the state, at a cost of $6,750, and this, added to the $8,000 directly appropriated to the survey for equipment, field work, and all other purposes, gives $14,750 as the total cost of the survey during these ten years; an average of $1,475 per annum.

Before going further it may be well to consider what was accomplished during this decade, to point out the advantages derived from this long period of preliminary work, and to call attention to some of its manifest disadvantages.

1) Every county in the state was visited, and the main features of the geology and resources of each were ascertained; descriptions were published of each of these counties, in some cases giving much detail; the main subdivisions of the geological formations in the state were established; the mode of occurrence and general distribution of the most important mineral resources were described and illustrated by many analyses; and the agricultural features of the entire state were given with an approach to completeness, thanks to the coöperation of the Tenth Census.

2) The experience and the knowledge of the territory acquired

by the state geologist during this long period, have unquestionably since been of benefit to the state, for without such experience on his part the disbursing of large sums and the directing of the work of the enlarged survey, so as to secure the best results and to avoid injudicious expenditures, would have been attended with many perhaps insurmountable difficulties. I might add further that the cost to the state of this preliminary work, as shown above, was small.

3) On the other hand, while at the beginning of the work these preliminary reports supplied in a measure the information then demanded, it cannot be denied that the progress of the state in the development of its great resources, especially in the latter part of this period created a demand for much more detailed and special information in certain directions than the survey could supply without some greater expenditure of money.

Second Decade.—Accordingly, a bill was brought before the General Assembly of 1882–83, providing for an annual appropriation of $5,000 for the ensuing ten years, and this bill became a law in February, 1883. Before the expiration of this ten-year limit the amount of the annual appropriation was increased in 1891 to $7,500; to continue till otherwise ordered by the General Assembly, thus avoiding the necessity of renewed legislation at every meeting. Under these laws assistants were appointed and work assigned as follows. Henry McCalley, in the Warrior Coal Field and subsequently in the Valley regions; Jos. Squire, in the Cahaba Coal Field; A. M. Gibson, in Murphree's Valley and the Coal Measures adjacent thereto, and afterwards in the Coosa Coal Field; the State Geologist, with D. W. Langdon, T. H. Aldrich, and L. C. Johnson, undertook the examination of the Cretaceous and Tertiary formations of the Coastal Plain. Administrative work, the editing of reports, and the preparation of the Geological Map, have however engrossed a great part of his time. Later, Dr. George Little made an examination of the clays of the Lower Cretaceous; Dr. W. B. Phillips began the investigation of the Gold region, and Mr. K. M. Cunningham has demonstrated

the existence of true chalk deposits in our Cretaceous formation.

Geological Reports published or in preparation.—Departing from the strict chronological order we shall state briefly the work accomplished and in hand in each of these divisions.

In 1886 was published McCalley's Report on the Warrior Coal Field, containing detailed sections of all the exposures of coal seams in the basin division of this field, together with Mr. Gibson's account of part of the plateau division. This report also contains the first approximately full columnar section of the measures of this field. In 1891 appeared McCalley's report on the Plateau region of the Warrior Field with map and colored sections. Mr. Gibson also contributed to this volume.

Active work has also for the past three years been going on and is still in progress under Mr. McCalley's direction in the Warrior Basin, in locating accurately the surface outcrops of the important coal seams. His examination of the Valley regions and their economic products, including iron ores, limestones, building stones, and bauxites, has been in progress for the past five or six years, and his report thereon is in great part written up.

In 1890 was published Mr. Squire's Report and Map of the Cahaba Coal Field. This document is the outcome of about thirty years'work, during which time Mr. Squire has been continuously engaged in this field either in active mining or in making instrumental surveys for individuals or corporations, all the results of which have been incorporated in his report. The map shows accurately the surface outcrops of all the important seams of coal, and a number of carefully constructed vertical and horizontal sections of the field. It exhibits also the geology of the adjacent valleys, compiled mainly from Mr. McCalley's notes by the present writer, who has also added a description of these formations and a sketch of their accumulation and subsequent history.

In 1884 the existence of phosphatic nodules and marls was discovered. The distribution, quality, and quantity of these materials were pretty thoroughly investigated by Mr. Langdon and myself, to form part of the coastal plain report; but the holding

back of this report for the map, and on account of active work in progress in the lower part of the state which it was desirable to incorporate therein, led us to issue in 1892, as Bulletin No. 2, an account of these marls in separate form.

In 1893 appeared Mr. Gibson's report on the Geology and Resources of Murphree's Valley, the publication of which had been delayed on account of the lack of a suitable map for its illustration. His report on the Coal Measures of Blount Mountain has just been published, 1894, and he is at work upon a preliminary report on the Coosa Coal Field.

Dr. Wm. B. Phillips, in 1891, undertook the examination of the gold region, spent part of one summer in the field work, and prepared a partial report thereon, but was unable to complete this work, and it was taken up in 1893 by myself and Mr. W. M. Brewer. It has been conclusively shown that these fields, with suitable methods of extracting the gold, can be worked in many places at a profit. The great activity now prevailing there leads us to think that the mining of gold will soon take an important place among the industries of the state.

Coöperation of the U. S. Geological Survey. Soon after the consolidation of the United States Geological Surveys into one organization in 1879, propositions were made by the director for coöperation with the state surveys, in accordance with which it was agreed that the U. S. Survey should make in Alabama accurately measured sections of our Paleozoic formations at two points selected after full consultation. This plan was afterwards slightly modified, and the results were published in 1892 as Bulletin No. 4 of the State Survey, a Report on the Geology of Northeastern Alabama and the adjacent parts of Georgia, by C. W. Hayes. This region in Alabama had already been pretty closely examined by the state survey, so that the change in the original plan caused some degree of duplication of work, but the mode of treatment of the subject and the map showing the connection with Georgia make this an exceedingly acceptable contribution.

Another result of this coöperation was a trip in 1883 down

the Warrior and up the Alabama rivers, made by L. C. Johnson and myself at the joint expense of the State and National Surveys, during which we collected the data for the first attempt at the stratigraphy of the Cretaceous and Tertiary formations of our Coastal Plain. The greater part, however, of the material afterwards brought together by the writer and published as Bulletin No. 43 of the U. S. Survey was collected in the following seasons, 1884–5–6, by the Alabama survey alone, by Messrs. Langdon, Aldrich and myself. Mr. Langdon afterwards carried these examinations across the state to the Georgia line, and thence down the Chattahoochee to Bristol, Fla., when he made the discoveries of the Chattahoochee and Alum Bluff series of Miocene formations, which have since become famous localities.

Although the joint trip of the present writer and Mr. Johnson, above mentioned, occupied only two weeks' time, Mr. Johnson was afterwards assigned by the U. S. Survey to independent work in this territory, especially in the examination of the post-Eocene formations, and it is to his work that we owe the greater part of our knowledge of the Grand Gulf and Pascagoula Miocene of this state. Mr. Johnson was also for one season in the employ of the state survey in completing the work thus begun. The present writer has also spent an additional season in this territory in 1891, and the coastal plain report above alluded to will contain the notes from all these sources.

It was feared by many that the extension of the U. S. Survey into the territories of the older states would have the effect of preventing the organization of new state surveys, and of causing the discontinuance of those already in existence, but the continuance or completion of existing surveys in New Jersey, Minnesota, Illinois, Indiana, Pennsylvania, Kentucky, Alabama and Wisconsin, and the organization of new surveys in Texas, Arkansas, Missouri, Georgia, North Carolina and Iowa show that these fears have not been fully realized. The national and state surveys occupy practically somewhat different ground, and so far from being antagonistic, they should be mutually helpful. In the case of Alabama it may be asserted that the coöperation of

the U. S. Survey has been very distinctly advantageous. In retrospect one can, however, easily see how these benefits might have been materially increased by more frequent conferences and consequently more thorough mutual understandings and adjustments.

Paleontology and Natural History.—With the small amount appropriated for the survey it would have been injudicious to use any of it on paleontology, but Mr. T. H. Aldrich contributed, without cost to the state, Bulletin No. 1, published in 1886, containing descriptions of new Tertiary fossils, with nine plates of illustrations. This is the first installment of what is designed to be a complete and illustrated account of our Tertiary paleontology.

So also Professor Herrick, of Denison University, contributed a List of the Fresh Water and Marine Crustacea of Alabama, with Descriptions of New Species, which was published by the Survey in 1887, as Bulletin No. 1 of Vol. V. This paper, which also appeared as a Memoir of the Denison Scientific Association, is illustrated by eight plates of figures of the species described.

From the beginning of the survey collections have been made by myself of the native plants of the state, and these collections, combined with those of Dr. Charles Mohr, of Mobile, were by him arranged and mounted, and the joint herbarium deposited in the cabinet of the University of Alabama. A preliminary list of the Alabama flora was printed in 1880, and Dr. Mohr is now engaged in preparing for the survey a report on the Botany of the state, in which every known indigenous phænogamous plant and fern will be listed, and full accounts given of the timber, forage, useful and noxious plants. The geographical distribution of the Alabama flora and the mapping of the botanical provinces of the state will be a valuable feature of this report, which is now far advanced towards completion.

In the progress of the work a new species of Croton of shrubby habit, *C. Alabamensis*, has been discovered, and many rare plants have been found growing upon our soil.

Geological Map.—Lastly, the preparation of the geological map of the state has engrossed a large part of the time and

attention of the state geologist for several years. The first difficulty to be overcome was the lack of a suitable base map. In this we had the aid of the U. S. Survey, in which office was compiled the first base map printed by the survey. As the work progressed numerous alterations and corrections became necessary, and not until 1893 was a satisfactory base map prepared. This map, on a scale of ten miles to the inch, with colors to show the geology, will be ready for distribution in a short time. It will be accompanied by a chart exhibiting the main lithological, economic, topographic and agricultural characters of each of the formations represented, and will embody the results obtained during the past twenty-one years.

Cost.—The cost of the survey during this period of eleven years, 1883–1893 inclusive, has been as follows:

Eight annual appropriations of $5,000	$40,000.00
Three annual appropriations of 7,500	22,500.00
Printing, binding, illustrating, and distributing reports	13,347.00
	$75,847.00

the entire cost averaging about $6,900 per annum. For the whole period of 21 years during which this survey has been active, the aggregate cost of the survey for all purposes has been $90,597, an average of $4,314 per annum.

Economic results.—Since the organization of the survey, the tax rate has been reduced over 50 per cent., without diminishing the revenues. The increase in the value of property in certain sections of the state that has rendered this possible, has been due in the main to the development of the mineral wealth of the state, and to this the survey publications have contributed a certain share, but how much it would of course be impossible to estimate. In this connection, however, it may be proper to say that some of the regions of the state in which the mining of coal and iron have since assumed vast proportions, were practically untouched by the pick of the miner, when our earlier reports directed attention by maps, analyses, and otherwise to their great resources: and very recently the survey has demonstrated the

existence, within the Coal Measures, of certain areas heretofore untried, in which the mining of coal will undoubtedly be profitable; it has pointed out a source of wealth in the phosphatic marls of certain sections; it has shown that gold may be mined with profit at many points within our limits; it has demonstrated the fact that clays suitable for the manufacture of fine porcelain ware, fire-brick, tiles, and other articles, occur in practically limitless quantity in many sections; it has pointed out the localities where good marbles and building stones may be had for the quarrying; all these have as yet not been turned to account.

Unsolved problems.—Of the problems of geological interest, developed in the course of the survey but not yet settled, I may mention the following: The stratigraphic relations of some of our Lower Cambrian formations are still uncertain; the relations between the formations of unquestioned Cambrian age, and the gold-bearing semi-crystalline strata adjacent to them and in some instances interlocking, are yet to be definitely fixed; the correlation of the seams of our three coal fields is still an unsolved problem, at least in its details.

Work yet to be done.—After the issue of the publications now in hand, the most important items of work proposed, are 1) The accurate mapping of the outcrops of all the coal seams of economic importance. The finishing of two or three of the sheets of the U. S. topographical survey will render this comparatively easy. 2) The preparation of county maps on the scale of half an inch to the mile, with accurate locations of all mineral deposits, mines, etc., as well as of the geological formations. 3) A republication, or rather a new edition, of the Agricultural report, with a map showing the distribution of the soil varieties. 4) An investigation of the water supply of the Coastal plain region, with special reference to Artesian borings. Much of the material for this is already in hand and in part published.

EUGENE ALLEN SMITH.

THE SUPERFICIAL ALTERATION OF ORE DEPOSITS.[1]

GENERAL FEATURES.

Scope of the subject.—The modern idea of ore deposits teaches that formations of this kind represent a process of concentration of mineral matter, either by chemical or physical means; in other words, that they are unusual localizations of certain minerals which are often found disseminated in smaller quantities in many common rocks, and that they differ from the same minerals situated in other conditions, only in their degree of concentration. These concentrations may take place at different times in the history of the rocks in which the deposits occur. If they occur in sedimentary rocks, they may sometimes be formed during the deposition of the rocks with which they are associated, as in the cases of placer gold, stream tin, and sometimes of other ores;

[1] The superficial alteration of ore deposits is a recognized principle of geology, in the same way as is the superficial alteration of any of the common rocks. Its importance in some classes of ore deposits is also well understood, as in many precious metal deposits; while in other classes, its importance has been proved in individual cases, as in the Lake Superior iron deposits. The causes and effects of superficial alteration in many classes of deposits, however, are not so generally understood, and it is the object of the present paper to show that such changes almost invariably give rise to exceedingly important chemical and physical phenomena, while in many deposits, the question as to whether they can or cannot be profitably worked, depends largely on the extent and character of this alteration.

The various treatises on ore deposits published in the United States and Europe make frequent mention of superficial alteration, but have not treated the subject fully. As early as 1854, however, before which time but little accurate information was had on the geologic nature of ore deposits, Professor J. D. Whitney in his classic volume, The Metallic Wealth of the United States, describes the alteration products, or gossans, in certain deposits and mentions others. On the more purely chemical side of the question, the work of Bischof, Daubrée, Roth, Rose, Hunt, Breithaupt, Blum, Julien, Deville, Debray, Volger, Moissan, Fremy, Lévy, Fouqué and others have afforded much valuable information and many useful suggestions. The chemical principles brought out by these various authors have been applied, to a certain extent, to the solution of the phenomena of the origin of ore deposits, but have not as yet been applied to anything like their possible extent to the solution of the phenomena of the alteration of ore deposits.

while if they occur in igneous rocks, they may sometimes be the result of concentration by differentiation from fused magmas.[1] More usually, however, ore deposits are a result of a concentration after the formation of the enclosing rock, whether the latter be of sedimentary or of igneous origin. The mineral matter represented in this concentration may be derived from the enclosing rocks or closely adjacent rocks, as in the case of many, if not most, iron ore deposits; or it may be derived from more distant sources, often from greater or less depths, as in some of the precious metal deposits. Occasionally, both these sources may be drawn on for mineral matter in one deposit. In this subject of the original source of an ore, we enter a field concerning which there has been much dispute of late years between the advocates of the lateral secretion theory and those who favor the idea of a deep-seated source for many ore deposits. It is not, however, the purpose of the present paper to enter into this discussion, and the following remarks are confined to what happens in the superficial parts of ore deposits, and to a less extent of allied formations, after the materials forming them have been brought into their present, or approximately their present, positions.

Relation of alteration in ore deposits and in country rocks.—Ore deposits are generally more or less changed in their upper parts by atmospheric influences, so that very rarely do the same mineralogical and physical features that are found in these parts, continue to very great depths. In considering this superficial alteration, we discuss a subject analogous to the secular decay of rocks. The latter, however, involves usually but a limited number of common rock-forming minerals, while the secular decay of ore deposits involves a great variety of minerals, not only the oxides, carbonates and silicates common in most rocks, but also sulphides, arsenides, tellurides, selenides, antimonides, chlorides, bromides, iodides, fluorides, sulphates, phosphates, tungstates, molybdates, and numerous other classes of minerals, many of

[1] This has been shown by J. H. L. Vogt (Zeitschrift für praktische Geologie, January, 1893) to be true of certain titaniferous iron ores and other deposits in the eruptive rocks of Norway. It may also be true of certain titaniferous iron ores in the United States.

which, under surface influences, give rise to intricate chemical changes. In discussing the subject of the superficial alteration of ore deposits, therefore, we treat a similar, but much less understood, subject than the superficial alteration of rocks.

Technical names of alteration products.—The altered surface outcrop of ore deposits is known by various names in different regions. Among the Cornish miners of England it is known as gossan, a name which has also been adopted into American mining nomenclature, though other special names are given in special classes of deposits. In France it is known as chapeau de fer; in Germany as eisener hut; among the Spanish Americans as pacos or colorados. As almost all deposits contain more or less iron minerals, the outcrops are usually stained brown from their oxidation, and hence the reference to iron in the French and German names. Sometimes, however, the outcrops are stained black by the oxidation of manganese carbonate or silicate, or green by copper minerals, or other colors by the formation of other compounds.

Agents of alteration.—The superficial alteration of ore deposits, as of any rock, results from a combination of mechanical and chemical disintegration, brought about by the combined action of the atmosphere, surface waters, changes in temperature, and the various organic and inorganic materials contained in the air and water. In nature, we never deal with perfectly pure water, but different waters contain different ingredients derived from the air and from the different materials with which they come in contact. Among the most important of these ingredients are oxygen, numerous organic acids like carbonic, oxalic, malic, citric, formic, propionic, butyric, acetic acids, etc., certain inorganic acids, such as sulphuric, nitric, hydrochloric, hydrobromic, etc., etc. Some of the acids mentioned occasionally occur in the free state, but most of them are generally combined with some of the bases present, such as the alkalies, lime, magnesia, iron, alumina, etc. These various ingredients, of course, are not all contained in the same waters, but are found in various associations in different waters. The organic acids mentioned represent

various stages of oxidation of materials from organic matter, but they all eventually, if allowed to become completely oxidized, pass into carbonic acid; while if they are in combination with different bases, these salts are eventually converted to carbonates.

Method and chemical effects of alteration.—Surface waters thus charged with various chemical ingredients percolate down into ore deposits, and there meet various materials which are even less stable under their influence than most of the common rocks. The alteration, therefore, is comparatively rapid, and, though only superficial, generally extends to much greater depths than in the surrounding country rock. From a chemical standpoint, the first effect of this superficial influence is usually the oxidation or hydration, or both, of certain ingredients, followed generally by the formation of other chemical combinations and by the leaching of certain materials. In the formation of these other chemical combinations, however, the base usually remains the same, and the alteration consists generally in a change of the materials associated with the base, that is, in the acidic portion of the mineral or the part that represents the acidic portion. Thus, iron sulphides are oxidized to iron sulphate, and then this is converted by further oxidation and by hydration to the hydrous sesquioxide. Copper sulphides may be oxidized to copper sulphate ; and from the sulphate, by the agency of materials in surface waters, may be formed copper carbonates, haloid compounds, silicates, oxides, and even metallic copper ; while from some of these, still other compounds may be produced. Similar reactions occur in many lead, zinc, silver, gold, and other deposits.

Occasionally, chemical changes may occur without previous oxidation, and sometimes, though rarely, surface influences under peculiar conditions may have a reducing effect, as in the formation of iron pyrites and copper pyrites from the sulphates of iron and copper, or in the formation of native copper by the action of a ferrous salt on certain copper salts, or in the formation of native silver in surface outcrops. In many of such cases, however, the chemical action is primarily one of partial oxida-

tion, and the reducing action follows as the effect of one of the partially oxidized compounds on the other, as in the case of copper just mentioned. In deposits, such as gypsum, a reduction, due sometimes to superficial influences, is seen in the occasional formation of sulphur from gypsum.

An important chemical effect of surface influences is the removal in solution of certain ingredients of the ore deposit which are soluble in surface waters; as the removal of the calcite gangue of many silver and other deposits; the oxidation and removal of the sulphur in various silver, lead, zinc, copper, and other deposits; the oxidation and removal of both the iron and sulphur of iron pyrites in auriferous quartz veins; the removal of silica from certain iron deposits, such as those in the Lake Superior region, etc. Probably many phosphate deposits are formed by the superficial leaching of carbonate of lime from calcareous beds, and the corresponding concentration of phosphate of lime once finely disseminated in the same beds.

Another chemical effect of superficial alteration is seen in the occasional formation of mineral deposits of importance by certain materials carried from outside sources and deposited in a rock of otherwise no commercial value. Thus certain phosphate deposits of the South Pacific Ocean, the West Indies and possibly of Florida, are formed by the leaching of soluble phosphates from guano, their transportation down into underlying limestone or coral reefs, and the precipitation of the phosphoric acid as tribasic phosphate of lime, which, being almost insoluble, arrests further escape of the phosphatic materials.

Again, another chemical effect is seen in the incrustations, and even extensive beds, of saline materials, like borax, nitre and the various alkaline salts of the western arid regions, formed by precipitation from water rising by capillary action through the soil, becoming evaporated on the surface and depositing the saline materials which they have dissolved from below. Many saline deposits are formed by the simple evaporation of surface waters, such as lakes, seas, etc., but certain deposits undergo only an initial concentration in this way, and are laid down with

clay, sand, and gravel, while further concentration is due to this capillary action. In the case of nitre, indeed, the saline material is very often, if not generally, formed in soils or guano beds and undergoes its first concentration by this capillary action.

In the various chemical changes mentioned above, the class of salts that remains, whether oxides, carbonates, haloid compounds, etc., varies with the nature of the bases affected. Thus, iron sulphides and copper sulphides are both oxidized and form sulphates. But here the similarity of their behavior ends, for the iron sulphate probably passes then into a basic sulphate and then into a hydrous sesquioxide, while the copper sulphate takes up carbonic dioxide and water and forms basic carbonates. The iron sulphate might, under certain conditions, form a carbonate in a similar manner, but this compound would be very unstable under the conditions existing in the alteration of sulphide deposits and would quickly go into the form of the hydrous sesquioxide, while the carbonate of copper is stable under existing conditions and remains.

In the same way, if silver sulphide and iron sulphide are both oxidized and then affected by waters carrying common salt or other chlorides in solution, the silver is converted to chloride, which is insoluble and remains; while the chlorides of iron are much less liable to be formed, as they are soluble, and some of them unstable, compounds, and even if they were formed, they would be leached out or oxidized. Hence, though chloride of silver is a common product of alteration in silver deposits, chloride of iron is never found, at least to any extent, as a product of alteration of iron deposits.

Again, it is frequently found that unaltered auriferous iron pyrites contains a certain amount of silver, while the altered part often carries almost none. In such cases, the gold has remained stable during the alteration, while the silver, in the absence of a chloride or other reagents to convert it to an insoluble compound, has been dissolved and carried away in solution by the acid materials generated during alteration.

Hence, the materials in surface waters affect different bases

differently, and, therefore, there is a great difference in the classes of salts formed by the same surface waters on the ores of different metals. In the same deposit there may be formed an oxide of one metal, a carbonate of another, a chloride of another, etc. In fact, in some of the silver deposits of southern New Mexico, there can be found hydrous sesquioxide of iron formed from iron sulphide, carbonates of copper formed from copper sulphides, and chloride of silver formed probably from silver sulphides, and yet in all probability the same surface waters produced all these changes practically simultaneously.

As a result of these various changes, certain materials are sometimes leached from the upper parts of ore deposits, which have become porous by alteration, and carried down to the less pervious unaltered parts. Here they are precipitated by meeting other solutions or in other ways, and hence the richest bodies of ore in a deposit often occur between the overlying altered part and the underlying unaltered part. This is not always the case, but it is true of some copper, silver, iron and other deposits.

Physical effects of alteration.—From a physical standpoint, the effect of superficial alteration is generally to make the deposit more open and porous, to cause it to shrink, and, in some cases, to convert it to a loose material of the consistency of sand and clay. In some cases, however, especially where considerable hydration goes on, an expansion may be caused. This is well seen in the formation of gypsum by the hydration of anhydrite, often causing an expansion sufficient to brecciate and fold the associated rocks,[1] and amounting to about 33 per cent. of the original material.[2] In the conversion of carbonate of iron to the hydrous sesquioxide of iron, or limonite, it has been found[3] that there is a contraction of 19.5 per cent., giving the deposit the loose porous structure characteristic of limonite and forming the familiar

[1] ELIE DE BEAUMONT, Explic. Carte géol. de France, Vol. II., p. 89. R. A. F. PENROSE, JR., Arkansas Geol. Survey, 1890, Vol. I, pp. 535-538.

[2] A. GEIKIE, Text Book of Geology, 3d Edition, p. 345.

[3] T. STERRY HUNT, Mineral Physiology and Physiography, 1889, p. 262.

limonite geodes.[1] In this case carbon dioxide has been removed from the iron, but oxygen and water have been added. A porosity is also produced by the removal of certain ingredients in an ore deposit without the addition of others, as in the oxidation and leaching of iron pyrites in veins of auriferous quartz, leaving a loose, porous, spongy quartz mass.

Surface decomposition has also, in many places, not only affected the ore deposit itself, but also the country rock in the immediate vicinity, and has converted it into a loose material of a sandy or clayey consistency, as at Iron Mountain, Missouri, in the Batesville manganese region of Arkansas and in other localities described beyond. In the iron and manganese deposits of the Cambrian and Lower Silurian rocks in the Appalachian region, the limestones and shales, which once enclosed the ore bodies, have often been converted to clay in the same way as in the Batesville region; and, in fact, the common mode of occurrence of these deposits is as residual clays carrying irregular bodies and nodules of ore.

This decay of the country rock in immediate association with ore deposits, is generally more extensive than in similar rocks not associated with such deposits, and, therefore, requires further explanation than the simple action of ordinary surface waters. The explanation is, doubtless, in many cases, that the rock has decayed under the influence of the same waters that originally concentrated the ore; and as these waters differed from most waters in character and in the materials they held in solution, they often had an abnormal effect. Moreover, when subsequently the ore body is affected by surface influences, sulphuric acid is liberated from sulphides and carbonic acid from carbonates, as well as other acids from other minerals, and all these materials have an active effect on most rocks. Moreover, the porous nature of many ore deposits, after they have been altered on the surface, allows a freer percolation of surface waters than elsewhere in the same country rock, and, hence, a correspondingly greater decay.

[1] R. A. F. PENROSE, JR., The Tertiary Iron Ores of Arkansas and Texas, Bulletin Geological Society of America, Vol. 3, 1891, pp. 44-50.

Another physical effect of surface influences on ore deposits is seen in certain forms of brecciation due to physical or chemical causes, such as expansion by hydration, etc. Such brecciation, however, has usually occurred in the country rock before the concentration of the ore deposit; in fact its existence, by offering favorable conditions for deposition, has often been the cause of the formation of the ore deposit in a given place. Though brecciation, therefore, is very important as a factor in the concentration of ore deposits, it does not belong, to any large extent, in a discussion of the surface alteration of ore deposits after their formation, and, therefore, it will not be treated further in this paper.

Depth of alteration.—Having thus discussed briefly the means by which superficial alteration in ore deposits is produced, and the results of this alteration, the next feature to be taken up is the depth to which it extends. As already shown, the alteration is primarily one of oxidation and generally of hydration; and, though either may occur without the other, they both very often occur together. When surface waters percolate into the rock, their influence is more active near the surface, because they carry large quantities of oxygen, and because the oxygen of the air itself also has some influence. As they sink deeper, the effect of the oxygen of the air becomes less active, and the oxygen dissolved in the water is consumed in oxidizing various materials which it meets on the way, until finally most of the oxygen is lost and active oxidation ceases. Theoretically, this oxidizing action may extend down as far as, and sometimes below, the level of the drainage of the surrounding country, which is called also the zone of permanent saturation. Above that level, there is a constant circulation of water from the surface downwards, thus affording means of active oxidation; but when the water reaches that level, not only has most of the oxygen contained in solution generally been used up, but also the circulation of the water is much more sluggish, so that oxidation is less active.[1]

[1] It is possible that the oxidation near the surface is due largely to free oxygen in the waters, while, when this becomes exhausted at a depth, the oxidation may be due to the abstraction by mineral matter of the oxygen in combination with materials in solution.

The process of hydration, when the materials affected do not require oxidation before they can become hydrated, may extend down indefinitely below the limit of oxidation; but when oxidation is necessary before hydration is possible, the latter process of course can extend no deeper than oxidation. Thus the silicate of alumina in feldspar may become hydrated and form kaolin without the intervention of oxygen. This is brought about by the action of carbonic acid and water, which react on the feldspar and form alkaline carbonates, kaolin and free or hydrous silica. Theoretically, therefore, kaolinization ought to go on to any depth that can be reached by water and its almost universal accompaniment, carbonic acid. In this case, however, the base in question is already in its peroxide condition ($Al_2 O_3$), but when a base is not in this condition, it frequently requires oxidation previous to hydration. Thus sulphide of iron does not become hydrated until it is peroxidized, and this mineral, therefore, requires oxidation previous to hydration.[1]

The various materials other than oxygen in surface waters have a very important effect on the mineral matter with which they come in contact, and their action sometimes takes place before that of oxidation, though it often requires at least a partial previous oxidation. The effect is both to form new chemical compounds with the materials involved, and to dissolve and bodily remove certain materials. As with oxygen, however, so with these other agents of alteration, they are more active above the drainage level of the country than below it, and an additional reason for this is that many of the materials affected require a primary oxidation before they enter into other chemical combinations. Thus sulphide of lead is oxidized to sulphate of lead before it can take up carbonic acid and form carbonate of lead; while on the other hand, carbonate of lime can be converted to sulphate of lime (gypsum) by the action of sulphuric acid or certain sulphates without any change in the degree of oxidation of the lime.

[1] For a full discussion of this subject see H. Rose, Ueber den Einfluss des Wassers bei chemischen Zersetzungen, Pogg. Ann. der Physik und Chemic, 82 et seq.

It will thus be seen that in going from the surface downwards, we pass from a zone of active oxidation into a zone in which oxidation practically ceases. Below the level of permanent saturation, the waters may sometimes gradually sink to very great depths, even deep enough to become intensely heated and possibly dissociated. Such water may have a very important effect in the formation of ore bodies, though in a manner quite different from their action on the surface. The present discussion, however, relates not to this, but to only superficial influences.

Though theoretically, therefore, alteration of one kind or another may extend down to, and in some cases much below the level of permanent saturation, and if given sufficient time would actually go to such depths; yet in many, if not most, cases it has not yet reached that level. The actual depth to which alteration does extend varies with the topographic conditions of the region, the chemical nature and the porosity of the deposits affected, the character of the climate, and other minor conditions.

The topography of a region affects the depth of alteration, because it is one of the principal features in determining the depth of permanent saturation. The chemical nature of the deposit affects the depth of alteration because on this depends the degree of resistance it will offer to the chemical effects of percolating waters. The porosity of the deposit affects the depth of alteration because, in deposits of similar kind but of different porosity, the more porous will be more accessible to surface influences, and will, therefore, be more affected, in a given time, than the less porous deposit.

The climatic conditions, such as the amount and manner of occurrence of rainfall and other forms of atmospheric moisture, and the rate and degree of variation in temperature have a large influence on superficial alteration. On the amount of rainfall and other forms of atmospheric moisture depends the amount of moisture available as an agent of alteration ; while on their mode of precipitation depends, other things being equal, the amount of water which would sink into the deposit, thus effecting alteration,

and the amount that would immediately run off the surface or be evaporated and thus have but little altering effect. The rate and degree of variation in temperature affect the amount of breaking in the rock by expansion and contraction, and, therefore, the accessibility of the rock to surface influences. The character of the climate also influences, to a certain extent, the nature and amount of vegetation, and from the vegetation are obtained many organic acids which assist the action of surface waters. In other ways, also, such as in the generation of nitric acid in the atmosphere, the character of the climate influences the agents of alteration.

As a result of all these influences, surface alteration is found to extend in different ore deposits to depths varying from only a few inches, or in fact only a fraction of an inch, to several hundred and even a thousand or more feet. In glaciated regions the products of decay have often been swept away by glacial action, and the time which has elapsed since then has not been sufficient for alteration to have extended to any great depths; while in regions of moist climates, the erosion sometimes, though not always, keeps pace with the alteration, so that the depth of the change is shallow. In those regions, however, which have not been recently glaciated and which have dry or only moderately moist climates, so that erosion is slight, or in places which have moist climates, but which, on account of their topography, are not subjected to very active erosion, the products of alteration collect, and the changes are traceable downwards often to great depths.

In the copper regions of Michigan, the deposits have been exposed to glaciation, and are still exposed to the active effects of erosion in a moist climate, so that here, though the native copper of the region is a material very easily affected by surface alteration, yet the only change observable is a slight stain of copper carbonate or oxide on the surface of some of the native copper, and even this is not always present. On the other hand, in the arid region of the west, most of which has not been recently glaciated and which has an exceedingly dry climate, the

residual products of alteration have accumulated to great thicknesses. This region, however, had once a much more moist climate than now, and some of the alteration may have occurred then. Many of the Arizona copper deposits in this region originally contained their copper in the form of copper pyrites, which, under similar conditions, is probably more resistant to surface alteration than the native copper of Michigan, and yet it has been changed to various other copper minerals for depths often reaching from 100 to over 700 feet. In Chile some of the copper sulphide deposits are said to have been altered to a depth of 1,500 feet, but it is very rare that much alteration extends in any ore deposits to greater depths than this. In the more moist climate of Tasmania, the results of alteration are also very marked.

The depth of alteration of ore deposits in unglaciated regions in the United States varies from a few feet to over 1,000 feet. In the Appalachian region, many of the deposits of auriferous quartz, iron pyrites, copper pyrites, etc., are altered to depths varying from less than one to a hundred feet or more. Many of the Clinton iron ore deposits are altered to still greater depths. The depth of alteration in these Appalachian deposits is usually much greater, other things being equal, south of the limit of glaciation than north of it. In the silver, lead, gold, and copper deposits of the Rocky Mountains and the western arid region, such as at Butte City, Leadville, Central City, Cripple Creek, Silver City, Lake Valley, Eureka, Virginia City, Park City, the Coeur d'Alene district, and elsewhere, the alteration has reached depths ranging from 50 to 600 or 700 feet, and in some rare cases still more. At Granite Mountain in Montana, signs of alteration are seen in the argentiferous quartz deposits of that region, even at depths of 900 feet, though of course at such depths the alteration is slight as compared with that nearer the surface.

Complete alteration rarely extends to these greater depths, and usually parts of a deposit which have as yet escaped alteration appear comparatively near the surface. These are at first very few and may be entirely enclosed by altered products, but with

increased depth they become more numerous and continuous, until they predominate over the altered products, and finally, when the limit of alteration is reached, they entirely replace them. The planes of contact between an ore deposit and the country rock, that is the walls, afford, when well defined, easy passages for the downward percolation of surface waters, and therefore alteration frequently continues down along these lines for considerable distances after the limit of alteration in the main part of a deposit has been reached. Any other possible channels, such as the planes of contact of different minerals in banded deposits or the series of drusy cavities often found in the central parts of ore deposits, may act in the same way as passages for water. Hence the not infrequent abundance of alteration products, such as hydrous sesquioxide of iron, and native copper and silver, along the walls and elsewhere in certain deposits.

Classification of the products of alteration.—The products of superficial alteration may be divided into two general classes: (1) Those which occupy the same position as the materials from which they were derived, or are only slightly removed, and possess the same general environment. Thus the altered outcrops of auriferous quartz and iron pyrites, of argentiferous galena, of sulphides of copper and many other similar deposits, represent alteration-products occupying the same general position as the original sulphide ores; while the iron ore bodies of the Lake Superior region represent alteration-products changed somewhat in position from that occupied originally, but yet in the same series of rocks and sometimes with somewhat similar environment. (2) In the second class are included those deposits which have been entirely removed from their original position and redeposited under totally different environments. Thus, placer gold deposits, stream tin, most of the deposits carrying platinum and the allied metals, magnetic and chromite sand, the gravels and sands carrying precious stones, and many other similar deposits represent this class. They have been derived by the decay and erosion of veins, dikes or country rocks carrying the materials now concentrated in these fragmental deposits.

The materials in their original environment may or may not have been sufficiently concentrated to serve as commercial sources of supply, but the fragmental deposits mentioned almost always represent a further concentration. This class of deposits is of great importance, but the present discussion relates more especially to the superficial alteration of deposits that remain *in situ*, and therefore these will be treated more in detail than the other class, (No. 2), though the latter will be mentioned as occasion requires.

SUPERFICIAL ALTERATION IN DIFFERENT DEPOSITS.

Alteration in iron deposits.—It was once generally believed that most iron deposits were the result of direct precipitation from aqueous solution, or in rarer cases, were igneous masses. It has long since been shown, however, that most workable iron deposits are the result of a concentration subsequent to their deposition, while very few are due to a direct precipitation during the formation of sedimentary rocks, though some may be due to a process of differentiation in the cooling of eruptive magmas.[1] The original presence of the iron in sedimentary rocks was doubtless due to a direct precipitation during the formation of the enclosing rock, but it was then in a finely disseminated condition, and it was only by being subsequently taken into solution again by percolating waters and concentrated, that it was converted into bodies of greater or less purity. Generally, though possibly not always, this process is superficial, and though it may extend to a depth of several hundred or even a thousand feet or more, it can be traced directly to surface influences, and its effects are seen to decrease gradually with depth. Shaler,[2] in 1877, showed that some of the limonites of Kentucky, Ohio and elsewhere were concentrations of iron derived in solution from shales and other rocks and reprecipitated in underlying limestone.

[1] See foot note on second page of present article.

[2] N. S. SHALER, Kentucky Geol. Survey, Report of Progress, Vol. III., New Series, 1877, p. 164.

Van Hise,[1] in 1889, showed that the iron deposits of the Lake Superior region are concentrations of iron formerly disseminated in a siliceous rock containing carbonate of iron and other carbonates, and called by him cherty iron carbonate. This disseminated iron was taken into solution by surface waters, carried down until its passage was obstructed or impeded by less pervious rocks, often dikes, and there precipitated by meeting with other solutions of a different nature. These other solutions contained oxygen, while the iron-bearing solutions had been largely robbed of their oxygen and had been freed from silica by the large amount of carbonic acid they contained. When, therefore, the two solutions met, the iron in solution was oxidized and precipitated; while the silica, in the spot where this precipitation occurred, was, on account of the dilution of the carbonated waters with the other waters, and through the agency of alkaline carbonates, dissolved and carried off, thus gradually increasing the amount of iron and removing the silica. By this theory, the iron is largely a replacement of the silica of the cherty iron carbonates, and has been derived from the parts of the strata exposed to superficial influences. The deposits are, therefore, of only superficial extent, though they may reach over 1,000 feet below the surface, yet when they pass below the action of surface influences, the iron has not been concentrated and they are of too low grade to be mined for iron ore. The methods of local concentration proposed by Professor Van Hise for these Lake Superior iron deposits, are equally applicable to certain other iron deposits, and are a most valuable addition to our knowledge of chemical geology. They also bring out in a most prominent manner, the fact that even rocks composed of materials like silica, which are very resistant to surface influences, may, under proper conditions, be replaced on a large scale.

[1] C. R. VAN HISE, The Iron Ores of the Penokee-Gogebic Series in Michigan and Wisconsin, Amer. Jour. Sci., 3d series, Vol. 37, 1889, pp. 32-47; The Iron Ores of the Lake Superior Region, Trans. Wisconsin Acad. Sci., Vol. VIII., 1891. For a fuller discussion by Van Hise on this subject see United States Geol. Survey, Tenth Annual Report, 1888-89, Pt. I., pp. 409-422; Monog. U. S. Geol. Survey, No. XIX., 1892.

The iron deposits of the Mesabi Range in Minnesota, which have lately been described by H. V. Winchell[1] are supposed to have had a somewhat similar origin to that given for the Michigan and Wisconsin ores by Van Hise. Winchell believes that they are due to the concentration by surface agencies of iron disseminated as oxides in a highly siliceous rock, and that in this concentration the silica has been replaced by iron.

The red hematites of the Clinton horizon of the Upper Silurian in the Appalachian region have been at least partly formed by superficial concentration which extends to only limited depths.

The iron deposits in other geologic horizons of the Appalachian valley, especially in the Cambrian, Lower Silurian and Carboniferous rocks, are also often much changed by the action of surface influences. Many of the deposits in the Cambrian and Lower Silurian can be clearly shown to be due to a superficial replacement of limestone, or even of more siliceous rocks like shales, by iron dissolved from ferruginous rocks in the neighborhood. In such cases, the iron in the original rock has been dissolved and carried off in carbonated surface water, and re-precipitated in the other rocks, all these stages being directly due to surface influences. Many of the carbonate iron ores of the Carboniferous rocks are rendered not only of higher grade, but also more easy to treat, by the oxidation of the carbonate to the sesquioxide and the removal of the carbonic acid. Moreover, these carbonate ores often occur as nodules, "kidney ores," in shale, and, on the surface, this shale has been softened by atmospheric conditions, thus facilitating mining; while away from the surface, the shale becomes harder and makes mining more expensive.

Surface influences on carbonate of iron have been made use of artificially in Styria, where a very hard spathic iron ore has been mined and spread out on a hill side for from 20 to 25 years. By this process the ore was oxidized and made more porous, and thus became very much more cheaply treated.[2]

[1] Minnesota Geological Survey, Twentieth Annual Report, pp. 136-148.

[2] Letter from MR. CHARLES E. SMITH, Philadelphia, Pennsylvania.

At the celebrated Iron Mountain in Missouri, a large part of the ore came from conglomerates composed largely of fragments of iron ore, which had been weathered out of the pre-Cambrian rocks that had originally contained them. These conglomerates lie at the base of the Cambrian strata which overlie the pre-Cambrian rocks, and even in the latter rocks, where exposed, the original ore has been made much more easy to work by the decay of the enclosing material and its conversion to clay.

In the iron region of eastern Texas, the limonite ores are often a result of the solution of iron from the superficial oxidation of iron pyrites, iron carbonate and glauconite. Sometimes the sequel of this process is the downward passage of the solution to an underlying laminated clay, and the gradual replacement of this bed, forming a hard limonite,[1] which still preserves the laminated structure of the clay.

In Mexico certain hematite deposits described by R. T. Hill[2] as occurring in Lower Cretaceous limestone at or near the contact with intrusive masses of diorite, and sometimes even in the diorite itself, may, as Hill suggests, be the result of superficial concentration from the limestone.

Very large deposits of hematite also occur in Grant county, New Mexico, at the contact of limestone and an eruptive. The origin of this ore is as yet somewhat obscure, but is probably due to a concentration after the original deposition of the iron.

The iron deposits in the lakes of Sweden and Norway are most striking instances of a concentration of iron ore due to surface influences and going on at the present time. The iron is derived from the oxidation of the neighboring rocks, carried by carbonated surface waters to the lakes, and there, by further oxidation and hydration, precipitated as hydrous sesquioxide (limonite). The iron ore is dredged up and used, but the processes of nature gradually replace it, and, in the course of years, the lakes again accumulate a considerable thickness of ore.

[1] R. A. F. PENROSE, JR., Geological Survey of Texas, First Annual Report, 1890, pp. 72–76, 79–81; also Bulletin Geological Society America, 1892, pp. 47–50.

[2] Amer. Jour. Sci., Vol. XLV., 1893, pp. 111–120.

Many other similar cases of superficial enrichment in iron deposits might be mentioned, but the above are enough to illustrate the point in question, and it will be seen that, of the regions which are the active producers of iron ore in this country, almost all, if not all, owe the existence, or at least the availability of their large bodies of ore, to superficial concentration.

Alteration in manganese deposits.—Manganese deposits are affected by superficial influences in much the same way as iron deposits. Many of the manganese deposits in the Cambrian and Lower Silurian rocks of the Appalachian Valley were concentrated in a manner somewhat similar, though not always so, to the iron deposits in the same regions.[1]

In the Batesville manganese region of Arkansas, the ore originally occurred in irregular masses in Silurian limestone, but surface decay has leached the carbonate of lime out of the limestone, leaving a red siliceous clay, which represents the less soluble part of the original rock. This clay now lies in hollows on the surface of the limestone and contains the masses of ore once disseminated through that rock. The removal of the carbonate of lime has concentrated the ore masses in the clay, and has also rendered them more easily mined; in fact, the only manganese ore that can now be profitably mined in this region is that in the residual clay.[2]

The frequent occurrence of deposits of bog manganese ore in the areas of crystalline rocks, generally represents a concentration of manganese resulting from the oxidation of disseminated carbonate and silicate of manganese in the country rock. This oxidation product is taken into solution in surface waters, and transported until subjected to such conditions that it is oxidized and precipitated as a hydrous oxide.

Alteration in copper deposits.—In many copper deposits superficial alteration has produced very remarkable chemical and economic results, and this is especially well seen in the copper

[1] R. A. F. PENROSE, JR., Journal of Geology, No. 4, Vol. I., 1893, pp. 356–370.

[2] R. A. F. PENROSE, JR., Manganese: Its Uses, Ores, and Deposits; Arkansas Geological Survey, 1890, Vol. I., pp. 166–209.

sulphide deposits of Arizona, Chile and elsewhere. In Arizona the upper parts of the deposits are composed of brown or black ferruginous masses, with brilliantly colored oxidized copper minerals, as cuprite, malachite, azurite, chrysocolla, etc.; while below, at depths varying from a few feet to several hundred feet, the deposits usually pass into a mixture of copper pyrites and iron pyrites, the latter usually being far in excess. Sometimes other copper sulphides occur, either mixed with copper pyrites or free from it, and they may or may not have been derived from it. Here the carbonates and some of the other alteration minerals contain not only more copper than the unaltered copper pyrites, but they are also in a much more concentrated condition than the sulphide which is disseminated through iron pyrites. The total amount of copper has not been increased, in fact it may be decreased by leaching, but it is in a more concentrated form, and therefore the ore obtained from these concentrations averages from eight to thirty per cent. or more in copper, while the mixture of unoxidized copper pyrites and iron pyrites below averages only about five per cent. in copper. Moreover, the altered ores are much more cheaply treated than the unaltered ones, and are therefore still more desirable. It will thus be seen that the economic value of the deposits as a whole has been greatly increased.

In the surface alteration of these deposits, the copper sulphides have first been converted to copper sulphate and then, by the action of surface waters and the materials contained in solution in them, they pass into the forms of copper carbonates, oxides, silicates, and occasionally to the chlorides and bromides, and sometimes to native copper. The iron sulphide is first converted to sulphate and then this, through other stages, is converted into the hydrous sesquioxide (limonite), though the iron sometimes now occurs in the form of the anhydrous sesquioxide (hematite). This may have been derived from the limonite by dehydration, or, under certain conditions, may have been formed directly by the oxidation of iron pyrites. The oxidized copper minerals in the upper part of

the ore deposit have been concentrated partly by segregation during alteration, and partly by the leaching of the associated materials. As a result of this, these minerals occur as seams, pockets or irregular bodies, often a hundred feet or more in diameter, generally enclosed by, and often intimately associated with, the oxidized iron materials which represent the gangue.

In the case of the Arizona deposits, alteration has progressed just far enough to increase greatly the value of the deposits without to any extent injuring it. Such products of alteration, however, are more or less soluble in surface waters containing various organic and inorganic compounds, so that in a moist climate there is a constant tendency to leach them out and leave only the less soluble parts of the gangue. In Arizona, this stage has not yet progressed to a noticeable degree, and one reason for this may be the extreme dryness of the climate, which affords opportunity for only comparatively slight percolation of surface waters.

In the copper deposits of Montana and the Appalachian region, however, a further stage of alteration is often observable. The copper deposits at Butte City, Montana, are composed largely of chalcocite, with copper pyrites, bornite, enargite, iron pyrites and other minerals in a siliceous gangue. On the surface the copper in these deposits has been almost entirely oxidized and leached out, and the ore consists of a porous, rusty, siliceous mass which was once mined for the small percentage of silver it contained. As depths were reached, the oxidized copper minerals began to appear, and eventually the sulphides formed the mass of the veins. In this case, a further stage of alteration is seen than that in Arizona.

At Ducktown in eastern Tennessee,[1] deposits of mixed iron and copper pyrites occur and have been altered in a somewhat similar manner on the surface. The copper minerals have been leached out of the ferruginous gangue in the upper parts of the deposits, and for a depth of from 20 to 80 feet or more, the deposits are composed simply of a porous mass of more or less

[1] J. D. WHITNEY, The Metallic Wealth of the United States, pp. 322–324.

hydrous sesquioxide of iron. Below this a part of the copper, which has been leached from above, has been carried down and deposited as a dark material, probably composed largely of oxides and sulphides of copper, and averaging sometimes 20 to 25 per cent. or more in metallic copper. This material immediately overlies the unoxidized mixture of copper and iron pyrites, which averages only from 2 per cent. to 4 or 5 per cent. in copper. The commercial copper mined in this region came from the part of the deposit below the iron capping and above the unoxidized sulphides. When this was exhausted, the mines had to be closed, for the unaltered sulphides were too poor to be utilized.

In Chile, Peru, and elsewhere in South America, changes in copper deposits, somewhat similar to those described in the United States, frequently occur. In fact, the great reputation which Chile once had as a copper producer, was largely due to this surface alteration, for the oxidized ore once supplied a rich and easily treated source of copper, but when the mines reached the unoxidized sulphides, the ores became poor in copper and more difficult to treat, so that the copper industry of Chile began to decline. In that region, however, the oxidation has in some places extended down as far as 1,500 feet.

Alteration in lead deposits.—In the case of lead deposits, the mineral galena, which is the commonest ore, is frequently more or less altered on its surface outcrops and converted to the sulphate (anglesite) and the carbonate (cerussite). The first product of oxidation is anglesite, but this is a soluble compound and readily unites with carbonic acid or soluble carbonates in surface waters, forming the carbonate of lead, or cerussite. In rarer cases, other lead minerals, like phosphates, may also be formed.

Alteration in silver deposits.—Galena deposits often contain silver, possibly sometimes in the same condition of sulphide as the galena, and this material is altered at the same time as the lead, with the formation of native silver, chloride of silver (cerargyrite), bromide of silver (bromyrite), iodide of silver (iodyrite),

and various other minerals. The native silver is formed, probably, only after a preceding oxidation of the sulphide. Deposits carrying other unaltered silver-bearing minerals, such as the various silver sulphides, arsenides, antimonides, tellurides, etc., are, when exposed to surface influences, affected in much the same way as the silver in argentiferous galena.

Alteration of zinc deposits.—In the case of zinc, the most common ore is the sulphide known as blende. This mineral, like galena, is generally oxidized on the surface, and forms by other chemical changes the carbonate (smithsonite), the basic carbonate (hydrozincite), and the basic silicate (calamine), in a manner similar to that described in copper and lead ores.

In the cases of both lead and zinc, oxidized ores are very desirable for metallurgical purposes, and are much sought after. To be sure, the carbonates, sulphates, etc., of lead and zinc contain less of these metals than the pure sulphides, but they occur in a more concentrated form than the sulphides, and, therefore, the ores containing them frequently carry as much or more of the metals than the ores containing the sulphides. Moreover, the oxidized ores are much more easy to treat and, therefore, have an additional value over the sulphide ores.

Alteration in gold deposits.—In the case of gold deposits, surface alteration has a most marked effect, and probably in no class of deposits is the change of more geologic and economic importance. The typical unaltered condition of gold in nature is in association with iron pyrites in quartz, the gold being sometimes in such association with the pyrites that it cannot be separated by mechanical means, while in rarer cases, it can be so separated. The effect of surface oxidation on such a deposit, is first to convert the iron pyrites into a hydrated sesquioxide of iron, which premeates the white quartz, with which the pyrites is usually associated, and turns it into a rusty brown mass. The next stage is the gradual leaching out of the hydrous sesquioxide by the action of surface waters. The iron is, in this way, finally removed altogether, and the remaining product is a pure white quartz, containing the gold which was originally in the

iron pyrites, and which has remained stable during the oxidation and leaching of that mineral. Such quartz is usually porous and spongy, and is filled with cavities which represent the shapes of the original crystals of iron pyrites, and which, during an intermediate stage, have been partly filled with hydrous sesquioxide. This leaching, however, is rarely complete, and the quartz is usually stained brown on the surface.

In gold deposits of this kind, other minerals, such as copper pyrites, galena, blende, etc., frequently occur, and when the deposit is affected by surface influences, these minerals act in the manner already described under copper, lead, and zinc. It is not uncommon to see gold-bearing quartz stained green by oxidized copper minerals, or black by manganese minerals. Sometimes, especially in the Rocky Mountain region, gold occurs in the form of a telluride instead of in iron sulphide, and in such cases, the telluride is oxidized and the gold set free from its combined state. The gold, in being freed from pyrites or other minerals, is not only concentrated by the removal of certain ingredients of the deposits, but it is brought into a condition in which it is much easier to treat than the unaltered part of the deposit, and, therefore, the upper parts of most gold-bearing veins are greatly enhanced in value. The ore from these parts is known as "free milling" ore, because it can generally be ground and the gold extracted by direct amalgamation with mercury; while the ore in the unaltered parts of the deposit cannot usually be thus easily extracted, but must be smelted or treated by chlorination or some other more or less expensive process.

When such deposits as those described are eroded, the particles of gold separate from the quartz and are concentrated in the streams as placer gold. These detrital deposits are the source of a large part of the gold of commerce, and, in fact, were once the source of most of it. Now, however, many of the richest placer deposits known have been exhausted; and besides, the methods of treating the ores in the original deposits are better understood, so that the latter are supplying yearly a larger and

larger percentage of the gold production of the world. Hence, it will be seen, that in gold deposits, surface alteration not only plays an important part in freeing the gold from the iron pyrites, but also in forming placer deposits. Detrital deposits similar to gold placers and carrying various other materials are not at all uncommon, as in the cases of the platinum group of metals, cassiterite, diamonds and many other gems, chromite and magnetite sands, and, in fact, even with some of the more common ores, as with the iron conglomerate at Iron Mountain, Missouri.

Alteration in tin deposits.—In tin deposits, the typical mode of occurrence of the metal is in veins, dikes, or country rocks, in the form of the oxide known as cassiterite. Cassiterite is not easily affected chemically by surface influences, so that it is not much changed by superficial alteration, but for this very reason, its concentration is most markedly affected by surface alteration, for in the erosion of tin-bearing deposits the masses of cassiterite are broken up and carried off mechanically by surface waters, to be deposited somewhere else in the form of gravel beds, instead of being dissolved and possibly disseminated. In this transition, the fragments of cassiterite are largely separated from the accompanying materials by reason of their greater specific gravity, and hence, gravel deposits rich in cassiterite frequently occur. These represent the stream tin of the miner, and have been formed in much the same manner as have the placer gold deposits. Some chemical action, however, has gone on in the tin ore itself, but this seems to have been simply a process of solution and redeposition, as is seen in the pseudomorphs of cassiterite after other minerals and in the impregnations of animal remains in Cornwall, such as antlers, with oxide of tin.[1]

Alteration in antimony deposits.—In many antimony deposits, alteration similar to that described in some of the deposits already mentioned frequently occurs. The metal occurs most commonly as the sulphide known as stibnite. By alteration, however, this passes into the oxides valentinite, senarmontite, cervantite, stibiconite, etc., or into the combined sulphide and oxide known

[1] J. H. COLLINS, Mineralogical Magazine, Vol. IV., 1882, p. 115.

as kermesite. Valentinite and senarmontite have the same chemical composition but differ in their crystalline forms. Native antimony sometimes occurs, and this also, by alteration, gives rise to the oxides.

Alteration in bismuth deposits.—The allied metal bismuth occurs most commonly as native bismuth, though the sulphide (bismuthinite), the selenide (guanajuatite), the telluride (tetradymite), etc. also occur. Native bismuth, by alteration, forms the carbonate (bismutite) and probably also the oxide (bismite) and the silicate (eulytite).

Alteration in mercury deposits.—In the case of mercury the metal commonly occurs as the sulphide (cinnabar), though other mercury minerals also occur. By the alteration of cinnabar and some of the other mercury minerals, metallic mercury is set free and occurs as globules or filling cavities in the ore.

Alteration in molybdenum deposits.—Another case of surface alteration in metalliferous deposits is that seen in molybdenite. This mineral is the sulphide of the metal molybdenum, and often occurs in quartz or calcite veins in the crystalline rocks of parts of Canada, and in many ore deposits of the Rocky Mountains and elsewhere. By surface oxidation, molybdenite passes into a brilliant yellow oxide of molybdenum, commonly known as molybdite or molybdic ocher, which, in the Canadian region, occurs as a powdery coating on the cleavage planes of the molybdenite.

Alteration in other deposits.—Superficial alteration like that already described in various deposits, occurs also in many others not yet mentioned, as in aluminum, nickel, cobalt, chromium, tungsten, and many rarer deposits, but the changes already described show the general features of the subject. It may be said, however, that one of the important ores of aluminum, known as bauxite, is probably derived from the alteration of feldspar under certain conditions; and its source, therefore, is not altogether unlike that of the hydrous sesquioxide of iron derived from the alteration of certain silicates. The conditions during formation, however, were probably quite different.

THE FORMATION OF HALOID COMPOUNDS IN ORE DEPOSITS IN ARID REGIONS.

The formation of chlorides and other haloid compounds has already been mentioned as one of the phenomena of superficial alteration in ore deposits. As soluble chlorides and sometimes other haloid compounds are common in surface waters, chlorides and the allied compounds are not at all uncommon as alteration products, especially in such cases as that of silver, where the chloride, bromide and iodide are insoluble compounds, and are not leached out. For this reason, chloride ores of silver are found to a greater or less extent in almost all silver districts in America, Europe, and elsewhere, but the occurrence of such compounds in very large quantities in certain parts of North and South America deserves special explanation.

Over a large part of the arid region of the west, lying between the Rocky Mountains and the Sierra Nevada, ores containing chloride of silver (cerargyrite) are abundant, and sometimes the bromides and iodides also occur; in fact, parts of this region are characterized by chloride ores. They are especially well developed in parts of New Mexico, Arizona, Utah, Nevada and other states and territories, and it seems probable that their abundance can be traced to the effect of the peculiar climatic conditions which have prevailed in that region in late geologic times. Most of this arid country was once covered with numerous bodies of water, some of them of great size. In late geologic times, however, these began to dry up, until their waters no longer rose high enough to have outlets, and then, as a natural result, they became highly impregnated with salt and other saline matter. Finally, they became desiccated, leaving deposits of various earthy and saline materials in their old basins, and among the most common of these was common salt. It seems probable that the abundance of chloride ores is due to the action of this salt on the pre-existing ore deposits of the region, in the basins of the lakes, and that the smaller quantities of bromides and iodides were formed by a similar action of the soiuble

bromides and iodides in association with the salt. Such ores, in some of the mines that have gone to sufficient depths, have passed into various other silver compounds, such as the sulphide (argentite), argentiferous galena, etc., which represent the original condition of the ores. This transition proves the chlorides and other haloid compounds to be of only superficial extent.

This transition to haloid compounds is not confined to silver ores, for the basic chloride of copper (atacamite) occurs at Jerome in Arizona, and both chlorides and bromides of copper occur in the Bloody Tanks district west of Globe in Arizona, though here, as elsewhere in Arizona, the other copper minerals already mentioned, such as carbonates, sulphides, etc., form the bulk of the copper deposits.

In parts of Mexico, Chile, and Peru, where saline materials have collected in a manner somewhat similar to that in the arid regions of the United States, the chloride of silver is one of the important ores mined, and it sometimes occurs intimately mixed with chloride of sodium, or common salt, forming the mineral huantajayite or the lechedor of the miners. The bromides of silver are also abundant in Chile, and, in fact, at the mines of Chañarcillo, a common ore is the double chloride and bromide known as embolite. Again, the atacamite, or basic chloride of copper, from the Desert of Atacama is well known.

It seems probable that this transformation of the silver and copper minerals did not necessarily occur exclusively while the deposits were covered by saline lakes, but may have occurred even more actively afterwards, when the surface waters were highly impregnated with chlorides from the residue left by the lakes, and when oxidation in the ore deposits was much more active than when they were covered by water. This seems all the more likely when we consider that the original silver and copper minerals probably had to be oxidized before they were converted to chlorides, etc. Of course the oxidation may have partly occurred before, or during, the existence of the lakes, but

in many cases it probably also occurred after they were desiccated.[1]

SUMMARY.

It will be seen from the above discussion that:

(1) After the deposition of ore deposits and their subsequent exposure to surface influences, such as air, water and the materials contained in it, changes of temperature, etc., chemical and physical alterations occur which cause a total change in the mineralogical condition, and generally in the economic value, of the ore deposit.

(2) The process of this alteration is primarily one of oxidation and generally of hydration, and both of these actions may go on alone, but generally both have their effect on the same material. The other materials in solution in surface waters also react on the substances in the ore deposit, either before or after the oxidation of the latter, though generally after at least partial oxidation, and form various compounds different from those originally in the deposit. The difference, however, with few exceptions, is not in the metal or other base which forms the important feature of the deposit, but in the acidic portion or material representing this portion of the mineral. Thus, sulphide of copper may be altered to carbonate of copper, but the base remains the same. The action of surface influences is in rare cases one of reduction, which, however, often follows a previous oxidation. The process of alteration also frequently causes a leaching of certain ingredients of the ore deposit, either with or without previous oxidation, as in the removal of iron pyrites, calcite, etc. It also sometimes renders a hitherto worthless material valuable by the introduction of a valuable constituent, as in the replacement of carbonate of lime by phosphate of lime. It also causes the concentration, by capillary action in soils, of certain deposits like nitre, etc. The compounds formed with different ore deposits vary with the ores affected and the sta-

[1] Chlorides of other materials than silver and copper may also have been formed by a similar process, but the solubility of many metallic chlorides would prevent their being accumulated in any but very dry regions.

bility of the compounds formed by the action of the materials in the surface waters on the constituents of the ores.

(3) The physical effect of superficial alteration is generally to make the deposit more open and porous, to cause it to shrink, and, in some cases, to convert it to a loose material of the consistency of sand and clay. In some cases, however, especially where hydration is active, and expansion may be caused.

(4) Superficial alteration extends downwards as far as surface influences are able to act, though generally alteration is not complete down to the possible limit. The depth of alteration depends on the topography of the region, the nature of the rocks, and on the climate. In glaciated regions, the glacial action has swept away the products of alteration, and sufficient time has not yet elapsed since then for alteration to have gone on to any great extent, but in many other regions the products of alteration have accumulated to considerable depths. The depth of alteration, under different conditions, varies from a fraction of a foot to 1,500 feet, or possibly more.

(5) Superficial alteration is well illustrated in iron, manganese, copper, lead, zinc, silver, gold, tin, and many other deposits. For special descriptions see text.

(6) The accumulation of soluble saline materials, like salt, on the surface has a very important effect in converting certain materials in underlying ore deposits to chlorides, etc.

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STUDIES FOR STUDENTS.

EROSION, TRANSPORTATION, AND SEDIMENTATION PERFORMED BY THE ATMOSPHERE.

IN dynamical geology there is one line of inquiry which has received, comparatively speaking, but little attention from American geologists. Our text-books discuss in a thorough manner the work performed by water, and they also tell us much about the work of earthquakes, of volcanoes, and of glaciers. Some of these phenomena appear so striking as always to challenge our attention. Others are so common in their occurrence and so obvious that they suggest themselves to our study and to our reflection everywhere. The work performed by the winds in the atmosphere appears hardly to have received its due share of attention. The transportation of solid materials by the air is one of those subtle operations in nature, which are apt to escape our observation. The process is of an unobstrusive nature, and only in certain localities becomes at all obvious. There are, however, some scientists who have understood and urged the great importance and efficacy of aerial transportation in geological dynamics. Ehrenberg, Von Richthofen and Pumpelly will be remembered first in this connection. Blake, Gilbert, Hayden, N. H. Winchell, Chamberlin, Merrill, and others have described instances of erosion and transportation by the atmosphere. But it will be conceded, I think, that the subject has not received any general and searching attention from geological students in this country. This is the only excuse for presenting at this time a few considerations bearing on the topic. I take the liberty to state in a dogmatic way what appear to me to be some laws governing aerial erosion, transportation and sedimentation in general. It is not claimed that these statements contain much that is new in substance.

As an agent of erosion air is far less efficient than water.

The chief circumstance on which this inefficiency depends is the small weight of the air, which is only about $\frac{1}{813}$ as heavy as water. Moving with the same velocity it will strike with a force only $\frac{1}{813}$ as great as that with which water will strike. The effectiveness of the impact, however, or the striking force, increases as the square of the velocity and thus when the velocity of the wind is 28 ($\sqrt{813}=28$) times greater than that of a current of water, the impinging force of the two currents is the same. Velocities 28 times greater than those of many rivers are not uncommon in the air a small distance above the ground. But the lightness of the air enables even a scanty vegetation to greatly slacken the speed in the currents immediately in contact with the ground. This slackening of the impinging current is apparently sufficient to effectually protect even loose soil from wind erosion under ordinary circumstances. Such is at least the case where the soil is moist and where the land is level.

As an erosive agent, the atmosphere is at a disadvantage also in another respect. Lakes never erode their bottoms below the plane of wave action, and even in rivers erosion is greatest at the shores where this plane meets the land surface. Were it not for the wave action, the erosion by continental waters, as well as by the waters of the oceans, would be greatly reduced in its efficacy. In fact we generally look at that part of the surface of the earth which is under water, as being an area of deposition and sedimentation, and at the land above water and the coast lines alone, as being areas of erosion. Whatever be the height of the atmosphere, it does not appear likely that its upper limit is a well defined plane with waves as on the sea. But even if it be, this wave plane would be high above the most elevated point on the earth's surface. There is, therefore, no plane of wave-erosion in the atmospheric sea. Such work of this kind as is performed by the air can only be compared with that which takes place in the ocean far below its plane of wave-action, and rather in its abysmal region. Evidently this is not very great, if of any consequence at all.

Wind erosion becomes geologically important only in certain localities, and the conditions favoring it are a dry climate and a topography of abrupt and broken reliefs.

On plains where the ground is dry and vegetation scanty or absent, ordinary strong winds are apt to slowly wear into the soil, where the roots of plants do not protect it. If such soil contains sand which is too coarse to be lifted up and carried away, dunes are formed, and the uneven topography thus developed still more favors wind erosion; for it is evident that the slopes of the dunes will be struck with greater force than the even surface of a level plain. In such places the sand grains are triturated and worn, and the abraded material is promptly removed. It is also evident that where a country is traversed by vertical escarpments and cliffs, and steep slopes, strong eddies are set up as the wind strikes these reliefs. Where the rocks are of fine materials and but little indurated, like most of the Mesozoic and Cenozoic beds of the west, it would be singular if such eddies did not erode the bare surfaces of their outcrops. It does not appear practicable to estimate separately the erosion produced by impact of the air alone, and the abrasion produced by the materials carried. The ratio between the two will, of course, vary with the quantity of the load. Where this is considerable, abrasion is no doubt proportionally greater than in water, for the speed of the impinging particles is here much higher, and their striking force consequently greater. Occasionally this circumstance greatly intensifies aerial erosion and produces a natural sand-blast, which is very effective in its action on solid rock. That such abrasion becomes appreciable and important along the escarpments of "mesas" in dry regions appears not to admit of a doubt. In such places the driven sand may sometimes be felt smiting the exposed skin of the traveler.

The speed of the wind being lowest near the surface of the ground, materials must by some means be lifted through this zone of low velocity in order to be transported any considerable distance by the atmosphere.

According to some observations made by Stevenson, the aver-

age velocity of the wind increases very fast and apparently not according to any definite law upwards for the first fifteen feet above the ground. Above this height it increases as the bisected chords of parabolas having their vertices in a horizontal line 72 feet below the surface. The parameters of these parabolas increase directly in the ratio of the squares of the velocities of the different winds. With a velocity of ten miles per hour at an elevation of fifty feet above the ground there will then be a velocity of about one hundred miles per hour one mile above the ground, but of less than one mile per hour near the surface. Observations made on the movements of clouds verify these calculations as to high velocities some distance up in the atmosphere. Whatever is to be transported any great distance must be lifted up to some considerable height above the surface of the earth, where the winds attain high velocities.

Over level plains, under ordinary circumstances, the conditions seem to be unfavorable for effecting any such upward transference, and little or no removal of material is apt to take place. But when a strong wind runs up against a vertical cliff, such as are seen in the bad lands or in the country of the plateaus and "mesas," eddies are no doubt set up which rise high above these vertical reliefs. A short valley or a reëntrant excavation in such a cliff will gather the wind and start it with increased force obliquely upwards, as it enters from the open end. In such a mobile element as the atmosphere an eddy like this may rise a considerable distance. No less effective in this respect are the whirlwinds in arid regions, which have been described by nearly every traveler in such countries.[1] During the warm part of the day these can be seen, it is said, at almost any time in some direction of the horizon. They often rise to a great height, carrying with them the loose materials of the desiccated soil and giving them up to the incessant and steady run of the winds above.

The explosive outburst of a volcano similarly launches enormous quantities of minute fragments of pumice on the currents

[1] GEO. P. MERRILL, Engineering Magazine, Vol. II., p. 599 *et seq.*

of the atmospheric ocean, throwing them upwards sometimes over 10,000 feet. Small quantities of incombustible matter are raised to the horizon of translation above by heated currents of air from chimneys and fires, and perhaps still smaller quantities by birds and other animals of flight.

Aside from these instances there are no important means by which the atmosphere is loaded, and for this reason, among others, its importance as a geological agent is small. The load to be carried must be raised before it is borne away. In water the contrary is almost always the case. The material to be transported is supplied at the water's surface and from the start to the end of the transport the sediments are allowed to slowly sink. They are transported forward and downward; in the atmosphere they must be transported first upward, and then forward.

To be subject to transportation by the atmosphere, rock materials must be finely comminuted, the average largest size of quartz particles that can be sustained in the air by ordinary strong winds being about .1 mm. in diameter.

This statement is based on a number of measurements, which have been made on sand and dust transported by the air. Among these are measurements of dust and sand raised by the wind from roads and streets in dry weather; of dust which fell on the ground at Kansas City, Mo., after a severe west wind on the plains; of dust collected after dry storms on the window-sills in residences in the central part of Kansas; of sand taken in crevices and corners in railroad cars in various parts of the country. It agrees with measurements made on volcanic dust known to have been carried several hundred miles in the atmosphere. Corroborating results have also been obtained by some simple experiments. The constituent materials of a coarse loam were separated into groups of different grades of fineness. These separations were thrown into the air and observations made on their behavior. The velocity of the wind was about eight miles per hour, and the observations may be tabulated as follows:

Average diameter of particles.	*Behavior of the particles when thrown into the air.*
.75 mm.	Described a path diverging about 10° from a vertical line.
.37 mm.	Described a path diverging about 45° from a vertical line.
.18 mm.	Described a path diverging but a few degrees from a horizontal line, were blown upward by eddies.
.08 mm.	Could scarcely be noticed to settle in transport.
.04 mm.	Apparently completely borne up by the wind.
.007 mm.	Completely borne up by the wind.
.001 mm.	Completely borne up by the wind.

It is hardly necessary to add that the average size of the largest particles carried varies greatly with the velocity of the wind. Sand grains will occasionally be found to have been thus carried, which have a diameter many times larger than the average maximum here stated. The presence of such large grains can readily be accounted for by the chances for becoming entangled in specifically lighter objects, such as fragments of leaves and other vegetation, and thus to be carried by them. It will be understood, also, that the statement made above does not apply to that phase of wind-transportation which takes place on the surface of a sand-dune, where the sand is as if rolled forwards, nor to that in the very lowest part of the atmosphere generally, where materials are thrown forwards short distances at a time by eddies due to the contact of the atmosphere with the more or less irregular surface of the land.

The capacity of the atmosphere for transporting particles of quartz below the size of .1 mm. in diameter, is very great.

Disregarding the occasional transference of matter by volcanic forces and by living organisms, there are only three principal agents known to be at work removing materials from place to place on the surface of the globe. These are water, ice, and air. It is believed that, with the above limitation as to the fineness of the material, the transporting power of the atmosphere, as compared with that of water and ice, is very great. The transporting capacity of the water in our continental rivers is better known than that of glaciers or of ice fields, and it makes our best

standard of comparison. Let us take, for instance, the work of transportation which is performed by the Mississippi river.

The efficiency of any transporting current is determined by three factors, viz.: (1) the area of its transverse section, (2) the velocity of its motion, and (3) its capacity for holding a load. In the case of the Mississippi basin we may say that the products of disintegration and erosion within its boundaries may be removed by principally two agents, water and air. What is removed by water all passes out through the channel of the lower Mississippi. The size of this current in transverse section is less than $\frac{1}{100}$ of a square mile. It is evident that all the materials removed by this river from its great basin, whether taken from the Rocky mountains or from the Appalachian highlands, must pass through the same narrow circumscribed limits of $\frac{1}{100}$ of a square mile in the lower course of the river. Now, the atmosphere may also be regarded as a current. The width of this current will be the average width of the entire drainage basin of the Mississippi, and in its height this current equals the height of the atmosphere. Taking this to be ten miles, which cannot very well be too much, and taking the average width of the Mississippi basin as one thousand miles—it is at least one hundred miles more—the transverse section of the atmospheric current will be ten thousand square miles. The ratio of the sizes of these two currents as shown in their sections is thus 1 : 1,000,000, *i. e.*, the cross section of the Mississippi current is $\frac{1}{1000000}$ of that of the atmosphere. If velocity and capacity for carrying a load were the same in both currents, the relative transporting power of the greater one would be 1,000,000 times that of the smaller.

In respect to velocity the Mississippi is also less effective in its work than the atmosphere above it. The average velocity of the wind over the interior basin is not less than eight miles per hour, while the average velocity of the lower Mississippi is about .7 mile per hour. The ratio of the velocities is therefore represented by the fraction $\frac{7}{80}$, which is a little less than $\frac{1}{10}$. If, therefore, the two currents were equal as to their cross sec-

tions and as to their capacity for sustaining a load, the current with the greater velocity would be able to remove ten units of sediments, while the slower current would remove one. Multiplying the fraction expressing the ratios between the cross sections of the two currents ($\frac{1}{1000000}$) by the fraction expressing the ratio between their velocities ($\frac{1}{10}$), we obtain a fraction which expresses their relative carrying power, if their capacities for sustaining a load were the same. This fraction is $\frac{1}{10000000}$. If every cubic foot of air in the atmosphere held in suspension as much of sediments as every cubic foot of water in the Mississippi, then the atmosphere would have the power to transport in a given time ten million times the quantity of material transported in the same time by the Mississippi river.

With regard to the capacity for holding solid particles in suspension the air is, however, greatly inferior to water. It is evident that the load which can be carried by the air at ordinary and even in high velocities, is a great deal smaller than that which can be carried by water. The capacity in this respect of any current depends on chiefly three factors: (1) the density of the medium, (2) its velocity, and (3) its viscosity. As to the comparative densities of the two fluids, the air is only $\frac{1}{813}$ times as heavy as water. Another circumstance also comes into consideration. When the particles of a material like quartz are suspended in water, they lose about $\frac{1}{2}\frac{9}{6}$ of their weight in the air, and the force with which they make their way downwards through the water is thus reduced to $\frac{1}{2}\frac{6}{0}$ of what it would be in the air. This still more increases the relative carrying power of water making it 1321 times as great as that of the air ($813(\frac{2}{1}\frac{6}{0}) = 1321$). On account of the greater average velocity of the atmosphere and also by reason of the consequent greater magnitude of its convection currents, this again has the advantage over water. But exactly to what extent these considerations affect the comparison, data are not at hand to determine. It would appear that the advantage connected with these greater convection currents more than outweighs the disadvantage due to the lesser viscosity of air, when compared with water. At such low

velocities and temperatures this difference in viscosity can perhaps be altogether disregarded. The relative power of the atmosphere to sustain a load of fine sediments would, therefore, appear to be no more than, say $\frac{1}{2000}$ of that of river water. But to be certain that this estimate shall not be too high, let us make the fraction $\frac{1}{8}$ of this value and call it $\frac{1}{16000}$. This means that if a cubic foot of water, *e. g.*, in the Mississippi, will hold in suspension 15.48 grams of solid particles[1], then the atmosphere above it can hold in the same manner in a cubic foot $\frac{1}{16000}$ of this quantity, or about .0015 gram. It will be remembered that this is true only for material of a certain coarseness. If it is too coarse, the atmosphere cannot hold it at all; while if it is very fine, considerably more can no doubt be sustained. In order to ascertain approximately the effect of the variation of the size of the particles on the quantity of materials which can be thus suspended in the air, and also to make sure that the above estimate of the total load of sediments which can be sustained is not too high, some simple experiments have been made. These consisted in introducing dust of varied degrees of coarseness into a receiver, and then keeping the air in the receiver in constant agitation at a velocity of about five miles per hour. A certain quantity of dust would in this manner be kept floating in the circulating air, and this quantity was found to vary with the nature of the material introduced. The results may be tabulated as follows:

Average diameter of particles.	*Quantity sustained in one cubic foot of air agitated to an average velocity of 5 mi. per hour.*
.08 mm.	.020 gram.
.04 mm.	.057 "
.007 mm.	.118 "
.001 mm. (and below)	.053 "

This apparently amply justifies the above estimate as to the quantity of dust which can be sustained in a certain bulk of atmospheric air. It is not supposed that the table gives exact determinations for the different materials, for the conditions of

[1] Humphreys and Abbott.

the experiment are of the most delicate kind and a slight change in the velocity will cause a considerable variation in the quantity of the load.

If then the ratio of the sections of the two currents is $\frac{1}{1000000}$, the ratio of their velocities $\frac{1}{10}$, and the ratio of their loads per unit of bulk of the two media is $\frac{10000}{1}$, the ratio of their respective transporting powers is as the products of these fractions, or $\frac{1}{1000}$. This is the same as to say, that if a cubic foot of air can hold in suspension $\frac{1}{10000}$ of the quantity of fine dust held in the same way by the water in the Mississippi river, and if the velocity of the winds in the atmosphere is on the average not less than ten times as great as the rapidity of the current in the river, and if the area of a vertical section of the atmosphere over the valley is 1,000,000 times as large as the area of a cross section of the lower stream,—then the capacity of the atmosphere to transport dust is 1,000 times as great as that of the river.

Atmospheric currents being loaded, mostly, only to the extent of an insignificant fraction of their capacity, their sediments will be better sorted than deposits in water-currents, which are more often loaded to their full capacity.

It is evident that the greater the load carried by any current, the shorter is the average distance from particle to particle while in transport. This increases the chances for the particles to be affected by each others' movements through the medium and thus for coming together to form clusters. This process, which has been called flocculation, causes more rapid sedimentation; for such a cluster of particles will fall faster through the medium than will the separate grains of which it is composed. Flocculation takes place among particles of all sizes, and small particles which would otherwise be retained in the supporting medium, will easily settle when collected into these clusters. Sediments which have been formed under such circumstances will hence contain a proportionally greater quantity of fine material than if flocculation had not taken place. But flocculation increases with the quantity of the load, and since the load of the atmosphere is

at least 1,000 times (under ordinary circumstances perhaps nearer 100,000 times) less per unit of bulk of the carrier than in most waters where sedimentation occurs, it is likely true that flocculation in aerial sediments is not as great as that which takes place in aqueous sediments. Thus the finest materials carried by the air are not deposited in so great a proportion with the coarse material, as they would be if the atmosphere carried a greater load. The finest sediments, say particles below .002 mm. in diameter, settle only during extreme calms, if not first caused to gather in flocculi. This extremely fine material is retained by the atmosphere and must be carried everywhere over the entire surface of the globe, and must also be deposited everywhere, but in such small quantities as not to be noticeable. No small part of it, it may be surmised, is carried from the land and precipitated into the sea. But the coarser sediments, say particles between .002 and .1 mm. in diameter, are less easily retained in the air and therefore occasionally deposited in favorable localities in such quantities as to become an object of geological significance. It is maintained that in these deposits from the atmosphere there should be a scarcity of the finest materials.

It should be remembered, however, that there are great differences in the prevailing wind velocities and that this circumstance will naturally bring together materials ranging through great differences in coarseness. It has lately been shown[1] that such differences are great, even within the limits of a minute of time. As a result there will be a chance for a considerable range in size of particles composing the bulk of any aerial sediment, a range which it is believed might be expressed for the diameters of such particles by the numbers 1 and 100. Of course the range of the extremes will be much greater.

Deposition of dust will take place where wind is caused to slacken its speed.

This is so self-evident that it appears superfluous to mention it. It may be presumed that such a slackening will take place over continental basins, where the general direction of the wind's

[1] S. P. LANGLEY: Internal Work of the Wind.

progress is transverse to the bounding highlands. It may also be presumed that the wind retards its velocity, when going down an inclined plane. The greater depth of the atmospheric ocean in these instances ought to have the same influence on the general current as the widening or deepening of a river channel. If this be the case with extensive continental depressions, valleys of rivers and smaller depressions of the earth's surface ought to produce somewhat similar effects in retarding the passing wind and inducing it to give up a part of the dust it may happen to carry along. On the other hand, when the wind passes over land covered by a growth of timber or only tall grass, its lowest part will be held comparatively still and will drop its load. Did the same air remain among the vegetation all the time this unloading process would stop with the first deposit, but as the eddies no doubt keep up a slow but constant exchange with the air above, the accumulation continues as long as there is any dust left.

Several important deductions can be drawn from the foregoing considerations.

The velocities in the atmosphere being so much greater than those obtaining in rivers, lakes, and seas, the distances over which materials may be transported in it will be correspondingly greater. In the sea sediments are carried out 200 miles and even farther. In the atmosphere, where the velocities often are 100 times greater than those in the sea, dust may, no doubt, be transferred a distance of several hundreds, if not a few thousands of miles. The very finest particles may be borne round the earth, as shown by the dust of Krakatoa, or may, indeed, circle about it for some time.

The greater depth of the aerial ocean renders it but little dependent in its movements on smaller elevations of the land. In a sea five miles deep an elevation of the bottom 8,000 feet high would interpose no serious obstacle to a general forward movement of the whole body of the fluid. Few of our mountain ranges exceed this height, and it would not seem impossible, therefore, that dust in some notable quantities should be carried

across a mountain range, provided there be a favorable current in the upper part of the atmosphere.

While the conditions requisite for much aerial erosion are limited to rather small areas on the land of the globe, there can be little doubt that deposition is much more general and widespread. For dust is carried everywhere. And if it be conceded that the atmosphere is never entirely free from dust, it follows that sedimentation occurs wherever and whenever there is a comparative calm. In places in the ocean, where sedimentation is known to be very slow, atmospheric dust may be supposed to form an appreciable part of the deposits.

The areas of deposition being much greater than the areas of erosion, it is evident the accumulations of atmospheric sediments as a rule are insignificant, only exceptionally exceeding on the land the secular erosion by water, and therefore accumulating only in such exceptional cases.

From a dynamical point of view the wind-theory would appear to furnish an adequate explanation of the occurrence of the loess in the Mississippi valley, at least as to most of its phases. The recent denudation of the western plains, of the bad lands, and of the Cordilleran plateau is extensive enough to furnish the materials many times over. The different rocks in these regions and the changeability of the atmospheric currents would combine to bring together and thoroughly mix a variety of materials, like those of which the loess is composed. The winds would naturally distribute over wide areas the heterogeneous but uniform mixture thus produced. When not taken close to exposures of other materials ninety-nine per cent, by weight, of the loess is composed of particles below the size of .1 mm. and it contains only a small proportion of the finest materials common in clays and residuary earths, just as must be the case in an atmospheric sediment. In the United States, lying in the zone of westerly winds, we find the loess in the continental basin east of the arid regions. It is best developed along the westernmost north-and-south drainage valley, that of the Missouri-Mississippi river. Almost everywhere it is heaviest nearest the

watercourses. In northeastern Iowa its distribution shows such remarkable coincidences with the distribution of the primeval forests, as to only leave the uncertainty whether the loess is the cause of the growing of the forest or the forest the cause of the accumulation of the loess.[1]

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[1] See Pl. XXII and XLIV, Eleventh An. Rep. U. S. Geol. Survey. MCGEE.

EDITORIALS.

THE circular of information regarding the Sixth International Congress of Geologists, to be held at Zurich from August 29th to September 2d, presents a most inviting programme of excursions, which may be taken by members of the Congress, in the picturesque and geologically famous regions of the Swiss Alps and the neighboring Jura Mountains. It is proposed to organize two groups of excursions conducted by geologists, many of whom have devoted the better part of their lives to the investigation of the country visited. The first group will be offered immediately before the meeting of the Congress, and is so arranged that those participating in them will arrive at Zurich a day or two before the opening of the Congress. These excursions will be devoted to various portions of the Jura Mountains. They will be organized in different towns, where those intending to take the excursions are to join the conductors of the parties. The second group of excursions take place immediately after the Congress adjourns, and will start from Zurich on September 3d, and will traverse the Alps by various routes, terminating at Lugano, about September 16th, where the Congress will be formally closed. There will be two classes of excursions. One class will be made on foot, in order that the geology of the country may be more carefully examined. The other will be by means of conveyances. The pedestrian excursions will necessarily be open to a limited number of persons, and warning is served that a certain amount of quasi-military discipline will be required by the leader, from which appeal may be made to the whole body of participants. The expediency of such a regulation will be apparent to all who have attempted to conduct similar tours. The second class of excursions will make use of railways, steamboats and carriages, and will aim to reduce to a minimum the distance to be gone over on

foot. The management of the details of transportation of these excursions will be entrusted to the agency of Messrs. Ruffieux and Ruchonnet at Lausanne ; their scientific direction will be undertaken by Professor Renevier and Professor Golliez, of the University of Lausanne, The first excursion of this sort will start from Geneva, where those participating in it will assemble on the 15th of August, and will spend thirteen days visiting localities in or near the Jura, including the environs of Geneva, Lausanne, Neuchâtel, Bâle, and the Falls of the Rhine. The second of these "voyages en zig-zag" will start from Zurich on September 3d, and will spend thirteen days in the most delightful parts of the Alps, visiting, among other points, the Rigi, St. Gothard, the Lake of the Four Cantons, the Jungfrau, the Matterhorn, and the Italian lakes. The cost of the first excursion is to be $60, and of the second $80.

Of the pedestrian tours, five are to take place before the meeting at Zurich. One, under the direction of Professor Schardt, of Montreux, will devote six days to the French Jura in the neighborhood of Geneva, the rendezvous being at Geneva, August 21st. The second, conducted by Professor Jaccard, of Neuchâtel, will spend five days in the Jura of Vaudois and in the neighborhood of Neuchâtel. The rendezvous is to be at Pontarlier, August 22d. The third excursion, in charge of M. Rollier, of Bienne, will spend six days in the Bernese Jura, the rendezvous at Delémont, August 21st. The fourth, under the direction of Professor C. Schmidt, of Bâle, will devote five days to the vicinity of Bâle and the country east of the Argovian Jura ; the rendezvous at Bâle, August 21st. The fifth excursion, under Professor Mühlberg, of Aarau, will spend five days in the Argovian Jura and in the neighborhood of Soleure. The rendezvous will be at Aarau, August 23d.

There will be four pedestrian tours after the meeting of the Congress, one under the leadership of Professor Heim, of Zurich, who will conduct a party over the eastern Alps of Switzerland from St. Gallen to Tessin, studying the compressed folds in the Säntis, and crossing the great Glärner double fold. Professor C.

Schmidt will conduct a party over the central Alps from Zurich to Lugano, visiting the "cliffs" of the Mythen and following the Gothard route across the crystalline axis of the Alps. Professor Baltzer, of Bern, will conduct another party over the Bernese Alps, from Lucerne to Tessin, examining the intricately plicated strata of the Gstellihorn, passing over the Grimsel and visiting the glaciers of the Unteraar and the Rhône. Professor Schardt will lead a party over the western Swiss Alps from Bulle, studying the complicated structure of the Alps of Freiburg, and crossing the Tête-Noire to Domo-d' Ossola. These excursions will furnish foreign geologists the best possible opportunity of becoming acquainted with the complex structure and widespread metamorphism which have become classic through the untiring energy and intelligent investigation of the Swiss Geologists. It goes without saying that all who can find the time and means at their command will avail themselves of these exceptional opportunities, and that the Sixth International Congress of Geologists will surpass its predecessors both in the number of members attending and in the benefits derived from the meeting.

J. P. I.

Reviews.

Geological Survey of Georgia: The Paleozoic Group: The Geology of Ten Counties of Northwestern Georgia, and Resources. By J. W. Spencer, A.M., Ph.D., F.G.S. (L. and A.), State Geologist. Published by Authority. Atlanta, Ga. Geo. W. Harrison, State Printer, 1893.

The state of Georgia has been somewhat unfortunate in the matter of Geological Surveys. That under the direction of Dr. George Little was discontinued before the publication of any extended report upon the work accomplished, and thus the results of a number of years of field work by competent geologists were lost to the state. The survey under Dr. Spencer was from the first heavily handicapped by the action of the Advisory Board in appointing the assistants without consultation with the State Geologist. It seems probable that this action of the Board will have the result of causing the loss to the state of all the work of the assistants so appointed. It is very much to be hoped that the Advisory Board will profit by past experience, and under the new organization will leave the choice of his assistants to the State Geologist, Professor Yeates, who is the successor of Dr. Spencer in this important position. Under no other conditions could a geologist with any justice be held responsible for the conduct and results of a survey.

The present volume records the work of Dr. Spencer in the Paleozoic terrane of Georgia, and a previously published report has dealt with the Tertiary and newer formations of the southern part of the state.

In chapter I, there is a general sketch of the geological structure of northwestern Georgia, in which are discussed in general terms, and in non-technical language, the formation and destruction of rocks; the effects of terrestrial movements on the growth of strata; the disturbances and dislocations of the original beds; the origin of valleys. In chapter II, the formations of northwestern Georgia are given in tabular form, with their equivalents in other states; in general the names first proposed by Dr. Safford for Tennessee find acceptance in

this report, as they must with all who have to do with the Paleozoic formations of the states adjacent to Tennessee, for the descriptions and classifications of Dr. Safford are remarkably true to nature. Chapters III to VI inclusive are devoted to a general description of the lithological and other characters of the different formations which make up the area under consideration in Georgia. The Ocoee group, which Dr. Safford places at the base of the Cambrian in Tennessee, or beneath the oldest of the fossiliferous strata, is mentioned by Dr. Spencer, but he does not enter into its detailed description. This group of semi-crystalline slates, often designated as hydro-mica schists, talcoid schists, and formerly as talcose schists, and which bears the greater part of the auriferous quartz veins in Georgia and Alabama, is extremely difficult to assign to its proper place in the series, in Alabama at least, for we find in the southeastern part of the Alabama Paleozoic terrane, some of the Knox or Montevallo shales slightly altered into partially crystalline slates, which we have not yet been able to discriminate from the unquestioned Ocoee. It has therefore seemed to us at least possible that the Alabama representatives of the Ocoee of Tennessee may be, in part at least, altered Cambrian shales. In chapter VIII the river alluviums and other formations later than the Carboniferous are mentioned, and it is interesting to find that remnants of the Lafayette, in the form of pebbles and red loam, are to be found in many places in the Coosa Basin at elevations of 100 to 150 feet above the present level of the waters in those regions. These same beds have been traced by the Alabama survey up the Coosa valley to the Georgia line, and they are also to be found extending from the west, for a good many miles within the Alabama line along the Tennessee river.

In chapter IX, dealing with the general physical features of the region, Dr. Spencer directs attention to the ancient character of the streams, and concludes that they long ago reached their base level of erosion, and have since been engaged in widening their valleys. In comparatively modern times (Lafayette), there has been a depression which has allowed the deposition of pebbles and loams at altitudes 80 to 150 feet above the present stream level, and of course a still more recent movement of elevation which has brought the streams to their present position. Probably the most striking memorial of these movements is to be found in the "flatwoods" of the Coosa Valley. This chapter is illustrated by a number of sections. Chapters X to XX

inclusive, are devoted to the detailed description of the local geology of each of the counties embraced in this region.

Part II (chapters XXI–XL inclusive) deals with the Economic Resources of the Paleozoic group, which are limonite, hematite, manganese ores, beauxite, coal, limestones, sandstones, and clays. The mode of occurrence of these materials, their distribution both geographical and geological, their analyses, etc., are shown forth in sufficient detail, and a commendable feature of Dr. Spencer's treatment is found in the explanations and suggestions as to the origin of these various ores, expressed in terms which are easy of comprehension even by those who have not had any special geological or chemical training. In this way the book has a direct educational value apart from the great amount of information as to local occurrences which it contains. The chapter on beauxite is of special interest, because of recent developments in the mining and shipping of this valuable substance from the Georgia and Alabama mines. The occurrence and general character of the ore in the two states are identical, in fact the ores belong practically to a continuous deposit, in close connection with the strata of the Knox Dolomite. On account of competition with the foreign beauxites, only the higher grades of the ore, containing from 55 per cent. and upwards of alumina, are shipped, and by far the greater part of this goes to the making of *alum*. This seems a wanton waste, since the inferior grades would answer for alum, and the higher grades should be reserved for the manufacture of the metal.

The coal of Georgia is confined to an area of about 200 square miles on the plateaus of Sand and Lookout Mountains. It is furnished almost entirely by two or three seams lying between the Upper and Lower Conglomerates near the base of the Coal Measures, as is the case also in Tennessee and the Plateau region of Alabama. In all this territory, these seams and the strata by which they are separated, are exceedingly variable in thickness. The most widely distributed of these is the Castle Rock seam just below the Upper Conglomerate (Main Etna and Cliff seams of Alabama and Tennessee). In Georgia the Dade seam, some 30 feet or more below the preceding, appears to be more extensively worked, and, in the sections given, of greater average thickness. This seam also has been worked in Alabama, where it is known as the Eureka seam. Still below this in all the states mentioned is another seam of great importance locally, the Red Ash seam.

In one locality, Round Mountain, which rises above the Lookout

Table land as a prominent eminence, an important seam is described by Dr. Spencer, which lies many feet higher up in the measures, and which so far as we know does not occur in that part of Lookout Mountain that extends into Alabama.

The clays described are of several kinds, (1) the kaolin-like clays, (2) the residual clays from the decomposition of limestones and calcareous shales, (3) the clays formed from the disintegration of shales, and (4) the alluvial clays. The first variety occurs in "horses" or in sheets or pockets in the residual earths from the decomposition of the strata of the Knox Dolomite and Fort Payne series. These are often quite pure and white, and have nearly the theoretical composition of kaolin. Although they occur in the residual matters they are not, according to Dr. Spencer, *residua* of the limestones, but are derived from the rocks of the metamorphic series.

The residual clays produce sometimes fairly good brick, but they are generally too rich in fusible materials to make fine products. Of greatest promise are the clays derived from the disintegration of shales and slates, some of which have given beautiful vitrified brick, such as would probably be well suited to serve as paving brick. The alluvial clays, especially such as belong to the Second Bottom deposits, in Georgia as well as in Alabama and Mississippi, furnish by far the greater part of the material for the manufacture of ordinary building brick, and it is of interest to note that the best quality of building brick along the whole Appalachian region is made from deposits of this character.

In chapters XL and XLI we have a plea for better roads, with numerous illustrations of country roads in Europe and America, which emphasize sufficiently well the contrast between good roads and bad ones. This is a seasonable chapter in view of the great interest now being awakened in the subject of better roads throughout the southern states.

Part III, chapters XLII to XLIV, is devoted to the discussion of the origin and characteristics of the soils derived from the various Paleozoic formations, and the composition of these soils is shown also by a number of chemical analyses.

An appendix containing acknowledgments and an account of the progress of the Survey, a classified table of contents and a full index conclude the volume. The base of the map has been compiled chiefly from the topographic sheets of the U. S. Geological Survey, and in the

mapping of the geological formations, Dr. Spencer acknowledges the valuable aid which he has had from the previous work of Dr. C. W. Hayes in this territory. The map shows in a very clear and satisfactory manner the areal distribution of the formations. We cannot, however, speak so much in praise of the cross sections, in which the vertical scale is so greatly exaggerated as to be quite misleading.

We consider this the most important of the official documents yet issued by the State of Georgia, and it is to be regretted that during his term of office Dr. Spencer did not have that complete control of the Survey that would have insured the publication of other reports of equal importance, especially one on the Crystalline Schists of the state.

E. A. SMITH.

Annual Report of the Geological Survey of Arkansas for 1890; J. C. BRANNER, State Geologist; Volume IV., *Marbles and Other Limestones*, by T. C. HOPKINS, 8vo., 443 pp., illustrated by cuts and plates, and accompanied by an atlas containing six sheets.

THIS volume is the latest of the series of volumes published by the Geological Survey of Arkansas. It is separated into three divisions, which are sub-divided into twenty-eight chapters. The first division is the introductory chapter on the "General Description of the Marble Area." After this comes Part I., which treats of limestones, including the following topics: "Composition and Origin of Limestone," "Varieties of Limestone," "Geologic and Geographic Distribution of Limestones," "Limestone as a Building Stone," "Miscellaneous Uses of Limestone," "The Carboniferous Limestones of North Arkansas," "The Silurian Limestones of North Arkansas," "Carboniferous Limestones South of the Boston Mountains," and "The Lime Industry of Arkansas."

Part II. treats of marbles, including the following topics: "The Origin and Uses of Marbles," "Marble in the United States," "Marble in Other Countries," "Marbles of Arkansas," "St. Clair Marble," "The Distribution of the St. Clair Marble," "St. Joe Marble," "Distribution of the St. Joe Marble," "Other Marbles found in Arkansas," "Quarrying, and Cutting, Dressing and Polishing Marble." In addition to this there is an appendix treating of the "Faults of the Marble Area of Northern Arkansas." Like many of the other

reports of the Arkansas Survey, this volume does not confine the discussion of the subject to Arkansas alone, but treats it also as a general proposition, thereby adding greatly to the usefulness of the report.

The general synopsis of the volume, given above, defines its scope. The marbles and other limestones of Arkansas are very properly discussed more in detail than any others, but a general description of these materials in other parts of the United States, as well as in the more important foreign localities, is also given. The author has not only given his own experience and investigations in the subject in Arkansas and other regions, but has collected in a systematic manner a large amount of useful information published elsewhere. He discusses also very fully the geology and chemistry of marble and limestones in general, as well as their various uses for ornamental and structural purposes, for making cement, burnt lime, etc. The discussion of the best methods of working and utilizing marbles and limestones, together with the plates illustrating these processes, will be of much use to the people of Arkansas, as well as elsewhere, in developing industries of this kind. The volume is really to be considered a text-book on marbles and other limestones, and not a report on the occurrence of these materials in Arkansas alone, though the treatment of the subject as related to that state is of course given prominence.

One of the most remarkable points brought out in the volume is the immense amount of marble contained in the state. In a belt of country lying north of the Boston Mountains and extending from near the Black River on the east to beyond Eureka Springs on the west, a distance of more than 125 miles, the marble is continuous, and the length of its winding outcrops as mapped is 2,812 miles. The combined area of the six maps necessary to represent this marble region is 4,450 square miles. This area extends east and west along the north slope of the Boston Mountains, on both sides of the White River and its tributaries, which run southeasterly in a general direction parallel with the mountains. The rocks are approximately horizontal, or dip gently to the south, and the marbles, which occur in both Silurian and Lower Carboniferous horizons, are exposed where they have been cut through by the creeks and rivers. The marbles vary greatly in quality and color, but many of them have been proved by practical tests made under the direction of the Geological Survey, to be of great strength and excellent quality. In color they vary from white to gray, pink, red, brown, and black, the gray, pink, red, and brown colors being the most com-

mon. In texture they vary from close grained, compact and granular to coarsely crystalline.

In spite of the large quantity and good quality of much of this marble, very little of it has been utilized and practically none of it has been shipped for outside consumption. The country is only very sparsely settled, and this fact doubtless accounts for the limited local use of the marble; while the lack of shipments to outside localities is explained by the want of transportation facilities, the ignorance of the existence of this marble among those who use such materials, and by the fact that many people have obtained a bad impression of the stone in general on account of a certain very poor grade of Arkansas marble used in building at Eureka Springs. The whole marble region is destitute of railroads, except at Batesville on the eastern end, and Eureka Springs on the western end, so that the use of a poor grade of this marble at a much visited locality like the latter place, was an unfortunate occurrence. The present volume will, therefore, do much good in removing these several difficulties. It will show some of the benefits to be derived by those who will introduce railroads into this country, which, indeed, is full of other resources besides its marble; it will bring the marble to the attention of builders and architects and all others interested in ornamental and structural materials; and it will also tend to overcome the bad impression given by the use of an inferior marble at Eureka Springs. Even without further railway facilities, the marble, as shown by Mr. Hopkins, could be cheaply shipped by water on the White River.

The chapter on "Carboniferous Limestones South of the Boston Mountains," is by Mr. J. H. Means, and is a careful discussion of the subject involved.

In conclusion, it may be said that the volume, besides containing a full discussion of the subject of marbles and other limestones, also gives much information on the geology of North Arkansas, and represents a large amount of careful geological work. The report is of much scientific and economic value, and reflects great credit on both Mr. Hopkins, through whose labors the great amount of work represented in the volume and the accompanying maps has been accomplished, and on the State Geologist, Dr. Branner, by whose liberal and broad minded policy, as well as by whose kindly interest in all investigations carried on under his supervision, such work is possible.

R. A. F. Penrose, Jr.

ACKNOWLEDGMENTS.

The following papers have been donated to the library of the Geological Department of the University of Chicago, mainly by their authors:

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—Eleventh report of the State Mineralogist for the two years ending Sept. 15, 1892. 612 pp. with plates and maps.

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